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Experimental Evaluation on Radio Interference Voltage Emission of HVDC Converter Valve Station Before and After Refurbishment

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Abstract

Radio Interference Voltage (RIV) emission from High-Voltage Direct Current (HVDC) converter stations is a critical Electromagnetic Compatibility (EMC) concern due to its potential impact on nearby communication systems and sensitive electronic equipment. Over long-term operation, ageing of converter valves, degradation of shielding, and deterioration of high-voltage hardware can lead to increased RIV levels, necessitating refurbishment. This paper presents a comprehensive experimental evaluation of RIV emissions from a back-to-back HVDC converter station before and after refurbishment. *In-situ* radiated interference measurements were conducted over a wide frequency range from 30 kHz to 1 GHz at identical locations and under comparable operating conditions, in accordance with IEC CISPR 18-2 and CIGRE Technical Brochure 391. The refurbishment included replacement of electrically triggered thyristor valves with light-triggered thyristor valves, enhancement of valve hall electromagnetic shielding, and renewal of associated high-voltage and grounding components. Comparative analysis of measured spectra shows a clear reduction in RIV emission levels after refurbishment, particularly in the lower frequency range below 1 MHz, with reductions of up to approximately 10 dBμV and smoother spectral characteristics. Measurements along the transmission line and within the performance perimeter further confirm reduced impulsive components and improved EMC behaviour. The results demonstrate the effectiveness of refurbishment measures in mitigating both conducted and radiated interference and provide practical validation and guidance for EMC-oriented refurbishment and compliance assessment of ageing HVDC converter stations.

Keywords: HVDC Converter Valve Station Refurbishment, *In-situ* RIV Measurement, RIV, RIV Spectra

1. Introduction

High-Voltage Direct Current (HVDC) transmission has become an essential technology for long-distance bulk power transfer, interconnection of asynchronous power systems, and efficient utilisation of large-scale generation resources. While HVDC systems offer significant operational and economic advantages, they also present Electromagnetic Compatibility (EMC) challenges that must be addressed throughout the lifecycle of a converter station. In that EMC challenges, Radio Interference Voltage (RIV) emission continues to be a critical concern due to its potential influence on nearby communication networks and sensitive electrical and electronic equipment[1].

Radio interference in HVDC installations originates from a combination of high-voltage discharge phenomena and high-frequency switching actions associated with commutation of power electronic devices. Corona discharges occurring on conductors, busbars, insulators, and other energised substation components are a major contributor, particularly under conditions of higher electric field stress. Additional emissions may result from intermittent arcing between components at different potentials, as well as from surface imperfections, sharp edges, installation defects, and ageing-related degradation of hardware. Within converter stations, the switching and commutation of thyristor valves generate broadband electromagnetic disturbances that manifest as both conducted and radiated emissions. The magnitude and frequency content of these disturbances are further affected by environmental factors such as

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insulator contamination, humidity, rainfall, and prevailing atmospheric conditions[2-9].

To ensure acceptable EMC performance and interference-free operation, internationally recognised guidelines have been defined for permissible limits for ra2dio interference emissions for HVDC installations. CIGRE Technical Brochure 391 specifies RIV emission limits for HVDC converter stations based on rated operating voltage and power capacity[10,11]. Compliance with these limits is essential to meet EMC requirements imposed by regulatory authorities. Accordingly, HVDC station equipment is designed, installed, and validated to ensure that the cumulative emissions from all sources remain within the prescribed limits under rated voltage and full-load operating conditions.

The level and origin of RIV emissions in a HVDC converter station evolve over the service life of the installation. At the time of commissioning, corona-related emissions are generally low due to clean insulator surfaces and new equipment, and interference associated with power electronic switching often dominates. These emissions include conducted components that propagate through electrical connections and radiated components that couple into the surrounding electromagnetic environment. Radiated emissions from converter valves are typically controlled through effective valve hall shielding. However, long-term operation can lead to reduced shielding effectiveness, increased surface roughness of conductors, accumulation of contaminants on insulators, and deterioration of hardware, all of which can enhance corona activity and create additional discharges, resulting in increased RIV levels.

Converter station refurbishment is undertaken not only to improve reliability and extend operational life, but also to address degradation in EMC performance. Refurbishment activities may involve upgrading or replacing converter valves, enhancing valve hall shielding, renewing high-voltage hardware, improving grounding and bonding arrangements, and restoring insulator surfaces through cleaning or replacement. These actions can significantly influence both the generation mechanisms and propagation paths of radio interference within the station.

A systematic comparison of radio interference voltage emissions before and after refurbishment provides valuable insight into the effectiveness of refurbishment measures in improving EMC performance. This paper presents an experimental investigation of RIV emissions from an HVDC converter station, based on *in-situ* measurements conducted before refurbishment and repeated after completion of refurbishment activities. For a fair comparison of emissions before and after refurbishment, radio interference voltage measurement was performed under similar operating conditions of the valve station and power transfer capacity. The measuring locations for comparison were identical. The measured emission levels are analysed and compared with the limits specified in CIGRE 391, and the impact of refurbishment on dominant emission sources is discussed. The findings contribute to a better understanding of RIV behaviour in ageing HVDC installations and provide practical guidance for EMC-oriented refurbishment planning and validation.

2. Method of *In-situ* Radiated Radio Interference Voltage (RIV) Measurement

Emissions originating from the converter valve hall and associated HVDC substation are measured/recorded at identified locations around them and on the enroute of transmission line using an antenna and EMI receiver. The measuring locations are selected in compliance with CISPR TB 391. Switching operation of power electronic devices emits a wide spectrum of radiations, and this radiated disturbance is to be measured in a wide frequency range, i.e., from kHz to GHz. In the present study, the RIV emission from the HVDC converter station was recorded from 30 kHz to 1 GHz. M/s. R&S make EMI test receiver along with three different antennas, viz. loop, bi-conical and logarithmic, which are used for measurement of *in-situ* RIV emission measurement. For a single sweep of emission measurement, three independent spectra are recorded/measured, in four spans of frequencies at different bandwidths, using one of the three antennas independently. Bandwidth, antenna frequency range and their height are fixed during measurement in each span of measurement and are given in Table 1.

Table 1. Type of antenna, its bandwidth and frequency range used for measurement

Spectra recorded	Frequency range (*MHz*)	Band width (*kHz*)	Antenna Used	Height at which the antenna is placed (*m*)
1	0.03 to 0.6	0.2	Loop	1.75
2	0.15 to 30	9	Loop	1.75
3	30 to 300	120	Bi-conical	3.5
4	300 to 1000	120	Logarithmic	3.5

In general, RIV emission at lower frequencies used to be higher in magnitude compared to that of other frequencies of

measurement interest. In many cases, measured disturbance in the lower frequency range is the deciding factor to assess valve hall shielding effectiveness and emission due to discharges. A loop antenna is polarisation/orientation sensitive and is used for measuring emission up to 30 *MHz* frequency. As per CISPR 18-2, the orientation of the loop antenna has to be identified at the measurement location for accurate recording of radiated emission at this vital lower frequency range. To identify the proper orientation of measurement, at the site of measurement interest, the antenna is fixed at about 1.75 m stand having a provision to adjust the orientation of the loop antenna for 360 degrees about its axis. Emission is recorded at 500 kHz as per CISPR 18-2 guidelines from 0 to 360-degree orientation. The orientation at which the receiver records maximum interference is considered the worst-case polarisation of the antenna, and further measurements at that location are performed at this identified worst-case polarisation of the loop antenna. The same procedure is followed for bi-conical and logarithmic antennas, too. For a bi-conical antenna, at 150 *MHz* frequency, the orientation at which the receiver reads the highest values of interference is considered as the worst-case polarization and further measurement at that location is performed in this polarisation. For a logarithmic antenna, the worst-case orientation is identified with a 500 *MHz* frequency. Both bi-conical and logarithmic antennas were placed at a height of 3.5 m from ground level. For a single sweep of emission measurement from 30 *kHz* to 1 G*Hz*, all three antennas are used independently in the designated frequency ranges. Measured/recorded interference level is represented in *dBμV/m*. The schematic representation of radio frequency interference measurement using different antennas at a particular location, 200 m from the shielded valve hall, is shown in Figures 1 and 2.

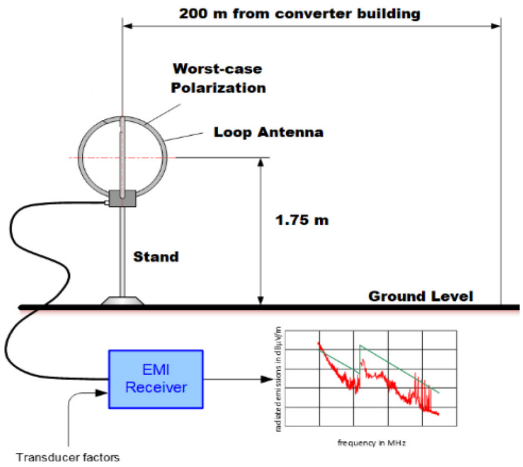


Figure 1. Arrangement of polarisation sensitive loop antenna for emission measurement in the frequency span of 30 kHz to 30 MHz.

Radio interference voltage emission is recorded using different detectors of the EMI receiver, viz. RMS, average, peak and quasi-peak, CISPR average, etc. Each detector has its own independent characteristics and is used for a specified measurement. As specified in CISPR TR 18-2 and CIGRE TB 391, the radio interference is to be measured with either a quasi-peak detector or peak detector or a combination of these two detectors. Interference measurement with a quasi-peak detector with linear frequency steps in the span of 30 kHz to 1 GHz consumes more time than that of other detectors. In the present tariff-based competitive bidding, utilities would like to complete the on-site measurement very quickly with lesser down time of the HVDC station. Compared to all detectors, measurement with a peak detector will be faster and less time-consuming. For the same bandwidth, the peak detector reads a higher value than that of quasi peak detector. Hence, for accurate measurement, as suggested in CISPR 18-2 and literature, the measurement is performed with a peak detector and on the measured spectrum, peak search is performed using a quasi-peak detector[9,12]. This combination will reduce the overall measurement time at the site. At one particular identified location, the radio interference is measured before and after refurbishment of converter valves and their associated substation equipment, in the frequency range of 30 kHz to 1 GHz. The measurements were performed from 30 kHz to 1 GHz using an appropriate antenna accordingly. However, distinct pattern changes have been observed on the *in-situ* measurement recorded up to 30 MHz and are predominantly considered for the assessment of emission characteristics of the HVDC station.

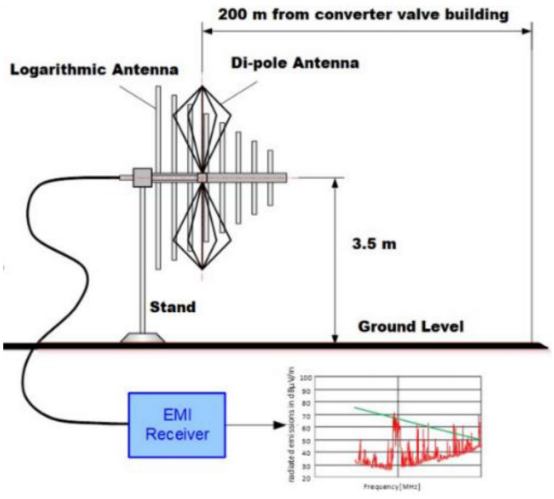


Figure 2. Bi-conical (dipole) and logarithmic antenna arrangement for emission measurement in the frequency span of 30 to 300 MHz and 300 MHz to 1GHz respectively.

3. Measurement Site

In 1989, the national utility commissioned the country's first 2 × 250 MW back-to-back HVDC converter station to interconnect two asynchronous regional 400 kV HVAC networks. In addition to enabling asynchronous interconnection, the station facilitates regional load sharing by transferring power from a surplus region to a region with higher demand. The BTB HVDC station was originally equipped with Electrically Triggered Thyristor (ETT) converter valves. After successful completion of about thirty years of service, to improve its life span and to provide a reliable power supply, the utility has decided to refurbish this HVDC station.

With advances in power electronics, particularly in thyristor technology, and with the objectives of reducing radio interference emissions and extending the service life of the installation, the utility undertook refurbishment of the HVDC converter station in 2020. The refurbishment scope included replacement of the existing ETT valves with Light Triggered Thyristor (LTT) valves, replacement of the converter cooling system, modernization of measurement and control systems, enhancement of valve hall electromagnetic shielding, replacement or refurbishment of high-voltage contacts in the substation, replacement of heavily polluted station insulators and surge arresters, strengthening of the earthing grid, and associated auxiliary works.

Both ETT and LTT converter valves generate Radio Interference Voltage (RIV); however, the dominant emission mechanisms, spectral characteristics, and coupling paths are different. Owing to the absence of complex electrical gate-trigger circuitry, LTT valves generally exhibit lower electromagnetic emission levels than ETT valves of comparable ratings. During normal operation of an HVDC station, a wide spectrum of interference is produced due to repetitive switching of the converter valves and electrical discharges from other energised high-voltage equipment within the substation. The magnitude and spectral distribution of these emissions depend on factors such as the number of valves, valve configuration, and switching speed. These emissions are required to remain within limits specified by applicable standards, manufacturer design criteria, and utility requirements.

Direct radiation from the converter valves is primarily mitigated by the electromagnetic shielding of the valve hall. Inadequate shielding effectiveness following refurbishment may allow interference to couple to nearby station equipment and transmission lines, potentially affecting the reliable operation of critical systems in the vicinity of the converter station. To ensure reliable operation of critical equipment and to validate the post-refurbishment station design, including switchyard components, assessment of radio interference emissions is essential. This comparative study enable better understanding of radio interference emission from station components.

4. Selection of Measuring Location at Measurement Site as Per CIGRE TB 391

Based on the station operating voltage level and power rating, CIGRE TB 391 has tabulated the radius of performance perimeter, d1, along which the maximum permissible limit of radio interference voltage emission from that station. Schematic representation of measurement points of interest for 400 kV voltage level and 500 MW capacity stations is shown in Figure 3[9]. As per CIGRE TB 391, the value of d1 is 200 m from the valve station, d2= d1⁄3, 66.7 m and d3 is 50 to 60 m at 1 km distance from valve hall. As per the guidelines, three measuring points were selected for measurement, two on the contour of the performance perimeter, i.e., at 200 m distance on both sides of the valve station building and a third measuring point at 1 km distance on the en route of transmission lines. As stated earlier, radio interference voltage emission is measured/recorded in the frequency range of 150 kHz to 1 GHz using an EMI receiver in conjunction with an appropriate antenna. Screenshot of spectra of RIV emission measured in the frequency range of 150 kHz to 30 MHz using loop antenna and EMI receiver with combination of peak and quasi-peak detector is shown in Figure 2. This screen shot indicates more or less all the detail of vital parameter used during measurement, viz. detector used along with its band width, attenuation level, details of measuring interval, i.e., linear or logarithmic, attenuation level and status of pre-amplifier during measurement including which detector is used for peak search on recorded spectra. It gives more detailed information than a regular frequency magnitude plot. For this reason, in the entire analysis, screen shot of the interference capture directly from the EMI receiver is used for analysis. To ensure precise measurement and an intention to record the comparable emission, at every measuring location, the spectra are recorded three times independently.

In addition to these measuring points, on utilities special interest, radio interference voltage measurement

was performed at four locations around valve hall within the performance perimeter in the frequency range of 30 kHz to 600 kHz. As per utility requirements, this emission measurement was performed using a peak and RMS detector at 200 Hz bandwidth using an EMI receiver and loop antenna. This measurement was performed at four different load conditions of the converter valve station, viz., valves ON with full load (250 MW), valves operating at 50% of load (125MW), valves operating with 25 MW of load and valves in blocked mode. At each of four locations identified inside the performance perimeter around valve hall, measurements were performed with these four different load conditions of the station. In total, sixteen measurements were performed in the frequency range of 30 kHz to 600 kHz with 200 Hz bandwidth using peak and RMS detectors. These additional measurement locations were selected to capture spatial variations in near-field RIV emissions around the valve hall and to assess the influence of different converter operating conditions on local electromagnetic interference levels within the performance perimeter.

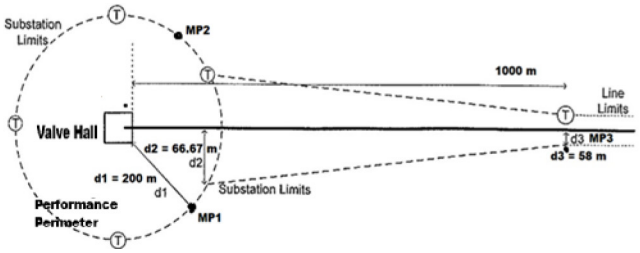


Figure 3. Schematic representation of the location of measuring points for the BTB HVDC converter valve station as per CIGRE TB 391[9].

5. Results and Discussions

5.1 Frequency Characteristics of Radio Interference Voltage Emission of Different Sources

In an electric power supply system, radio interference voltage emission mainly originates from discharge activities and the operation of power electronics devices. Primary sources of emission are mainly

a. Due to corona and spark discharges
b. Due to the commutation of HVDC and FACTS devices.

Relative strength and frequency characteristics of emission, as in CIGRE TB 391 is given in Figure 4.

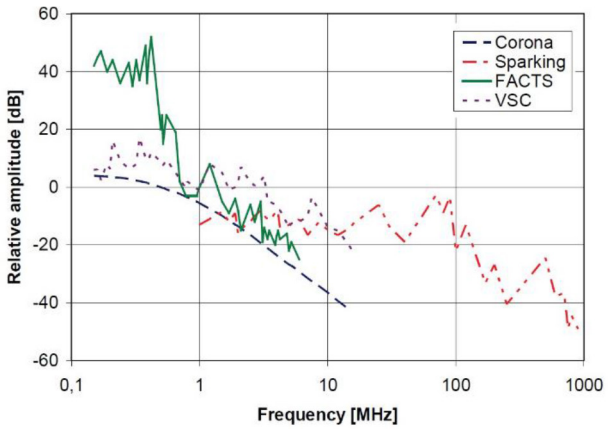


Figure 4. Typical relative frequency spectra for radio interference voltage emission from discharges and operation of power electronic devices in electric power systems [CIGRE TB 391].

It may be observed that emission from spark discharges is present from 1 MHz to 1 GHz at different strength levels. Emissions from FACTS devices are predominant at lower frequencies and their relative strength decays as frequency increases; however, it spans up to 10 MHz frequency. Emission discharges from corona activities and voltage source converter valves are also more or less in this frequency range only; however, their relative strength is less compared to FACTS devices. Using the relative strength and frequency characteristics of interference, the recorded RIV emission before and after refurbishment of converter valves and their station equipment is analysed.

5.2 Comparison of *in-situ* RIV Emission Recorded at Measuring Point 1 On The Contour of Performance Perimeter Before and After Refurbishment

Figures 5(a) and 5(b) show the RIV spectra recorded using an EMI receiver at a distance of 200 m from the valve building at Measuring Point 1 (MP1) of the BTB HVDC converter valve station before and after refurbishment, respectively. The EMI receiver screenshots include detailed measurement settings to ensure a fair comparison. The selected measuring point was located on the switchyard side of the station.

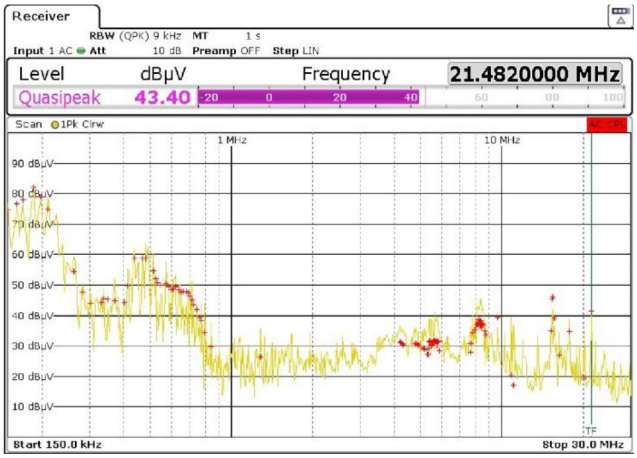


Figure 5(a). Screenshot of radio interference voltage emission recorded in the span of 150 kHz to 30 MHz at measuring point 1 on the contour of performance perimeter before refurbishment, when the valve station is in full operation.

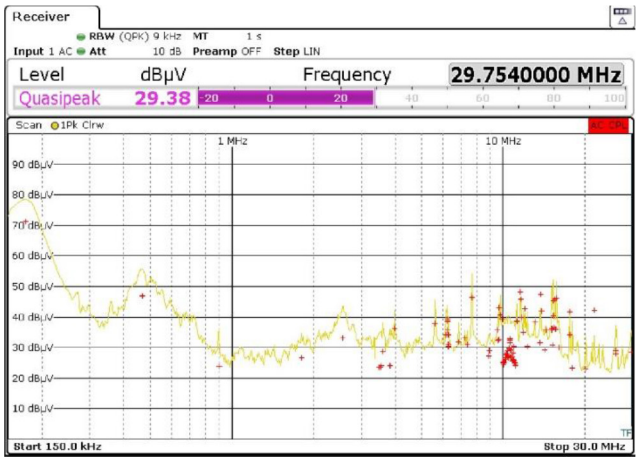


Figure 5(b). Screenshot of radio interference voltage emission recorded in the span of 150 kHz to 30 MHz at measuring point 1 on the contour of performance perimeter after refurbishment, when the valve station is in full operation.

Measurements were conducted with all converter valves in service and the station operating at its rated power transfer capacity of 500 MW. Measurements before and after refurbishment were performed at the same location and at the same time of day. Fair weather conditions with comparable ambient and climatic parameters prevailed during both measurements, ensuring that the contribution of atmospheric noise to the recorded RIV was essentially similar.

Comparison of the measured spectra indicates that the overall interference characteristics before and after refurbishment are similar; however, the post-refurbishment spectrum exhibits improved smoothness. At approximately 500 kHz, a reduction of about 10 dBµV in RIV magnitude is observed relative to the pre-refurbishment condition. This reduction may be attributed to the replacement of electrically triggered thyristor valves with light-triggered thyristor valves. In addition, the absence of pronounced peaks and abrupt spectral variations after refurbishment suggests reduced corona and/or sparking discharge activity from associated high-voltage equipment. The mitigation of such discharge phenomena within the converter station and switchyard resulted in an overall reduction of RIV emission of approximately 10 dBµV. In other frequency ranges, no considerable pattern changes were observed in the recorded spectra other than smoothness. The magnitude of the emission level was also comparable. It may be interpreted that the contribution of FACTS devices of radio interference emission from HVDC converter valve stations is more or less similar in magnitude. However, the absence of corona and spark discharge activities due to the refurbishment of associated station equipment has reduced the recurrence of RIV spikes. Quasi peak detector measures not only the magnitude, but also how often a similar pulse is reoccurring / or repeatedly emitted. It is evident from a screenshot of recorded interference emission that the refurbishment activity has reduced the impact of emission considerably.

5.3 Comparison of *in-situ* RIV Emission Recorded Along The Transmission Line At 1 Km Distance From The Valve Station Before And After Refurbishment

RIV emissions recorded along the en-route transmission line at a distance of 1 km from the converter valve station are presented in Figures 7a to 7f. Measurements were carried out over the frequency ranges of 150 kHz–30 MHz, 30–300 MHz, and 300 MHz–1 GHz using loop, biconical, and logarithmic-periodic antennas, respectively. The receiving antennas were positioned at an approximate lateral distance of 50 m from the outdoor transmission line conductor. At this measurement location, which is significantly remote from the converter valve station, radiated emissions originating directly from the station are considerably attenuated[9]. Consequently, the recorded interference represents a combination of emissions propagating along the transmission line from the valve station and locally generated emissions arising from corona and spark discharge activities associated with transmission line conductors and insulators.

As evident from Figures 5(a) and 5(b), a substantial reduction in the overall interference magnitude is observed after refurbishment of the converter valves and enhancement of the valve hall electromagnetic shielding. Similar to the measurements performed within the performance perimeter, the pre-refurbishment spectra exhibit pronounced sharp spikes, whereas the post-refurbishment spectra are characterised by a comparatively smooth emission profile. Although the general spectral trend before and after refurbishment remains similar, a clear reduction in emission magnitude and a near elimination of impulsive components are observed following refurbishment.

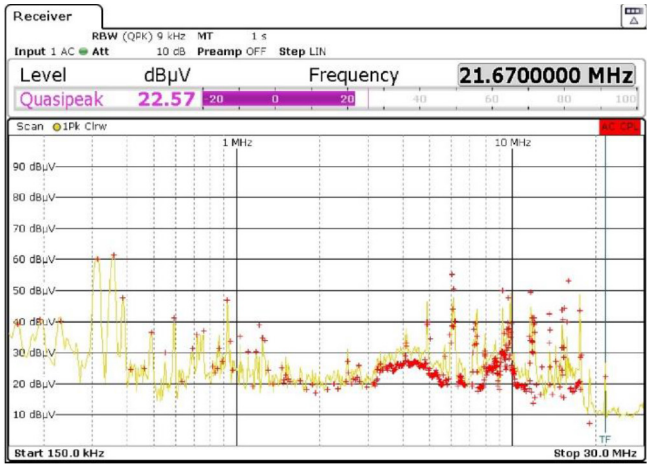


Figure 6(a). Screenshot of radio interference voltage emission recorded in the span of 150 kHz to 30 MHz along the transmission line at 1 km distance from valve hall before refurbishment, when the valve station is in full operation.

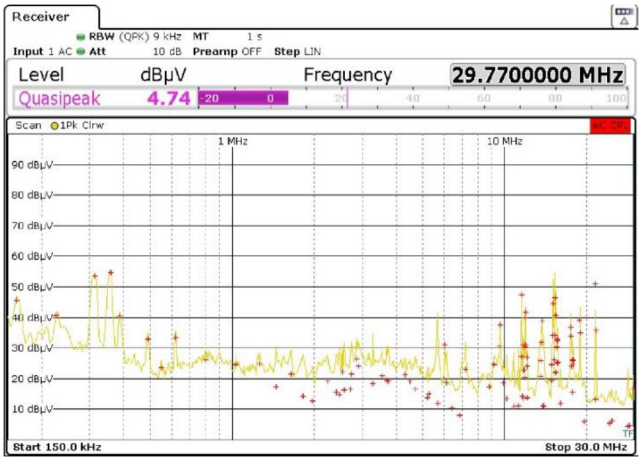


Figure 6(b). Screenshot of radio interference voltage emission recorded in the span of 150 kHz to 30 MHz along the transmission line at 1 km distance from the valve hall after refurbishment, when the valve station is in full operation.

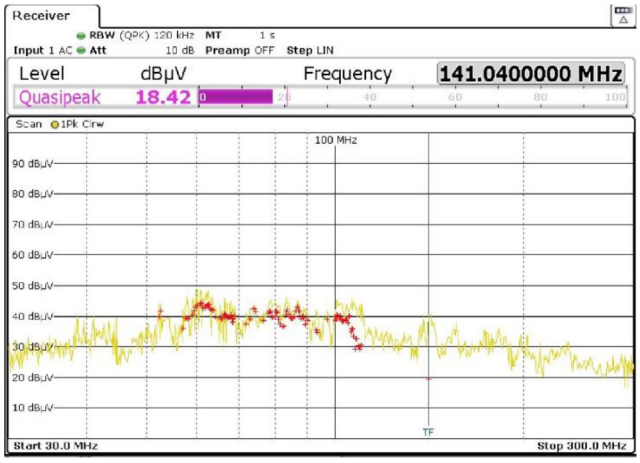


Figure 6(c). Screenshot of radio interference voltage emission recorded in the span of 30 MHz to 300 MHz along the transmission line at 1 km distance from valve hall before refurbishment, when the valve station is in full operation.

The measured spectra in the frequency range of 30–300 MHz, shown in Figures 6c and 6d, exhibit comparable behaviour. In this band, the emission trends before and after refurbishment remain largely unchanged, with only marginal differences in magnitude. The absence of sharp spectral spikes in the post-refurbishment measurements indicates a significant reduction in spark discharge activity along the transmission line.

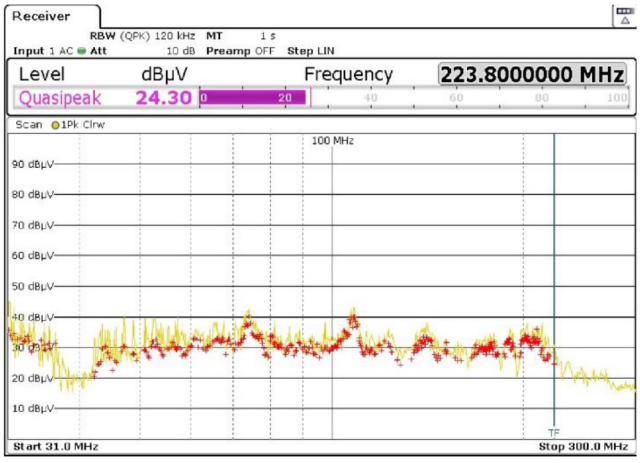


Figure 6(d). Screenshot of radio interference voltage emission recorded in the span of 30 MHz to 300 MHz along the transmission line at 1 km distance from the valve hall after refurbishment, when the valve station is in full operation.

A similar reduction in interference levels is also observed in the higher frequency range of 300 MHz–1 GHz, as shown in Figures 6e and 6f. The consistent reduction

across all frequency bands confirms the effectiveness of the refurbishment measures in mitigating both conducted and radiated interference components propagating along the transmission line.

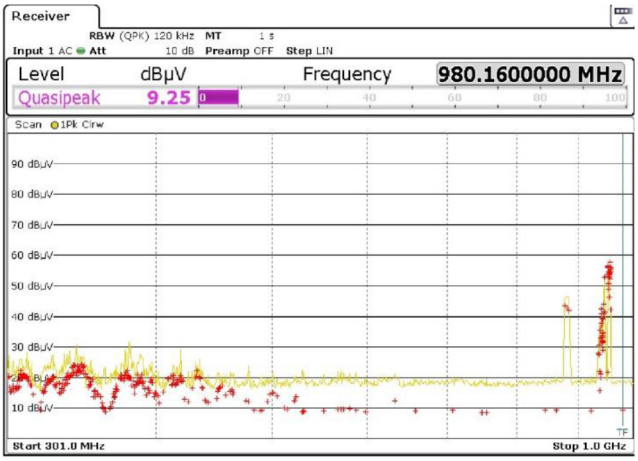


Figure 6(e). Screenshot of radio interference voltage emission recorded in the span of 300 MHz to 1 GHz along the transmission line at 1 km distance from valve hall before refurbishment, when the valve station is in full operation.

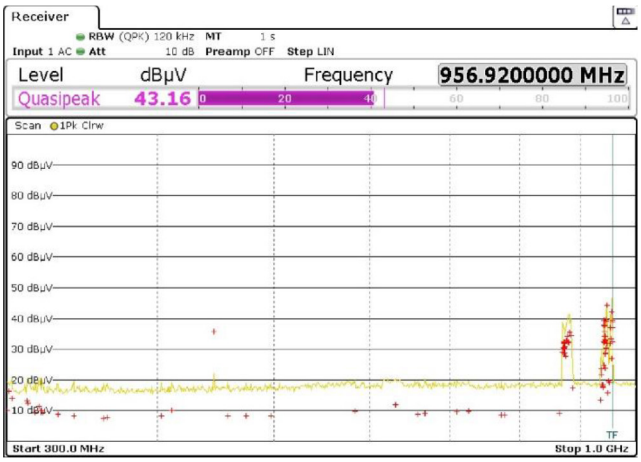


Figure 6(f). Screenshot of radio interference voltage emission recorded in the span of 300 MHz to 1 GHz along the transmission line at 1 km distance from the valve hall after refurbishment, when the valve station is in full operation.

5.4 Analysis of Radio Interference Emission Recorded on Near Field

Near-field electromagnetic interference measurements were conducted at a distance of 50 m from the converter valve hall, corresponding to the performance perimeter defined in CIGRE TB 391. Measurements were performed under rated operating conditions, with the HVDC converter station operating at 100% load transfer capacity to represent the worst-case emission scenario, i.e., with all converter valves in service. The interference spectra were recorded using a loop antenna connected to an EMI test receiver employing both peak and RMS detectors over the frequency range of 30 kHz to 600 kHz, with a resolution bandwidth of 200 Hz.

The measured radio interference levels exhibit a clear dependence on the operating load of the converter station. The highest emission levels occur during full load transfer, when all converter valves are energised. Under partial load operation, the reduced number of active valves results in lower interference levels, whereas at zero power transfer, only the auxiliary systems remain energized and the recorded emissions are minimal. To account for spatial variations in the radiated electromagnetic field, measurements were performed at all four locations distributed around the converter valve station.

Figures 7a and 7b present the interference spectra measured at Location 1, situated on the south side of the converter valve station at a distance of 50 m from the valve hall before and after refurbishment of the station, respectively. Both peak and RMS detector responses were recorded simultaneously. A direct comparison shows that, over the frequency range of 150 kHz to 600 kHz, the post-refurbishment interference levels are consistently lower than those observed before refurbishment.

According to CIGRE TB 391, radio interference in this frequency range is predominantly associated with the operation of power electronic equipment such as voltage source converters and FACTS devices. The observed reduction in emission levels following refurbishment is therefore attributed to modifications introduced in the converter valve system, including changes in valve design and switching behaviour.

In addition to the reduction in overall emission magnitude, a noticeable change in the spectral distribution of the measured RIV is observed after refurbishment. This change indicates an alteration in the emission characteristics of the converter station, consistent with the modified operating characteristics of the refurbished power electronic components.

Intermittent narrowband components are observed in the frequency range of approximately 300–400 kHz in the post-refurbishment measurements. These components do not exhibit stable frequency positions or repeatable

spectral signatures across successive measurement intervals. Consequently, they are attributed to transient external electromagnetic disturbances or localised electrical discharges in the vicinity of the measurement location during the measurement period, rather than to steady-state emissions from the converter valve station.

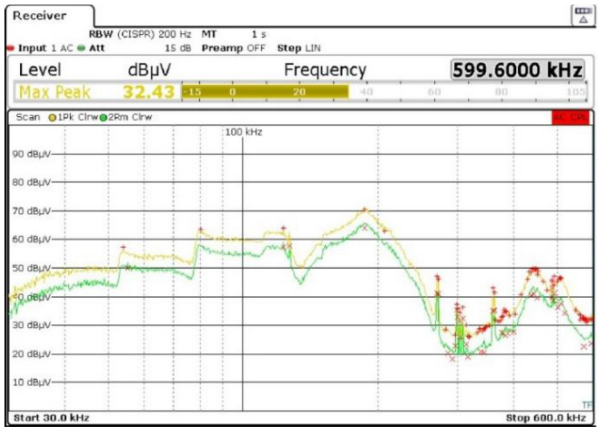


Figure 7(a). Screenshot of radio interference voltage emission recorded before refurbishment in the span of 30 kHz to 600 kHz near the converter valve station when the station is operating at its 100 % capacity.

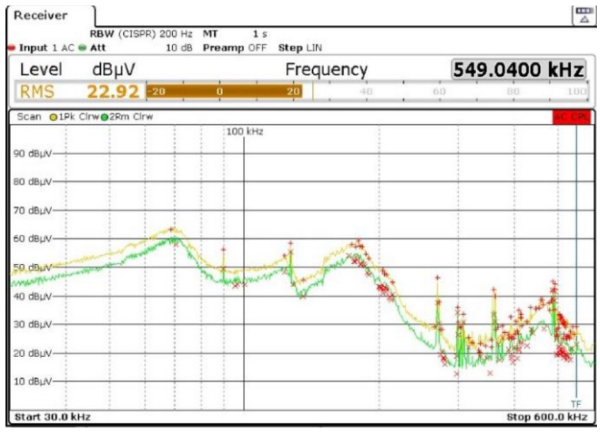


Figure 7(b). Screenshot of radio interference voltage emission recorded after refurbishment in the span of 30 kHz to 600 kHz near the converter valve station when the station is operating at its 100 % capacity.

Figures 8a and 8b show the RIV spectra recorded at 50% load injection for the pre- and post-refurbishment conditions at the north side of the valve station, respectively, while Figures 10a and 10b present the corresponding spectra at zero power transfer. In both operating conditions, the post-refurbishment measurements demonstrate a significant reduction in interference magnitude compared to the pre-refurbishment case. This improvement is attributed to the replacement of converter valves and the enhancement of electromagnetic shielding of the valve hall implemented during the refurbishment. Magnitude of RIV recorded before and after refurbishment of the converter valve station with different load injection in near field measurement is given in Table 2.

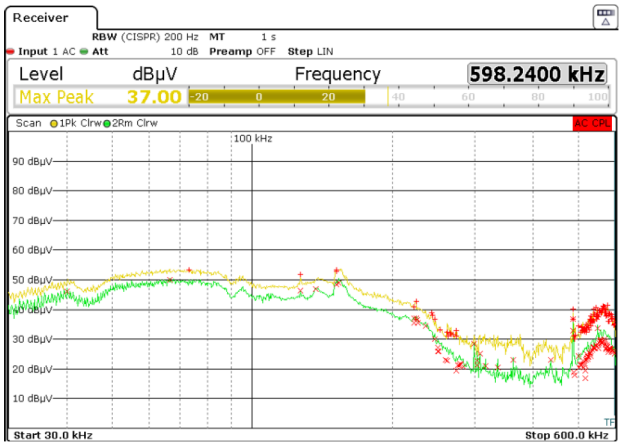


Figure 8(a). Screenshot of radio interference voltage emission recorded before refurbishment in the span of 30 kHz to 600 kHz at the north side of the converter valve station when the station is operating at its 50% capacity.

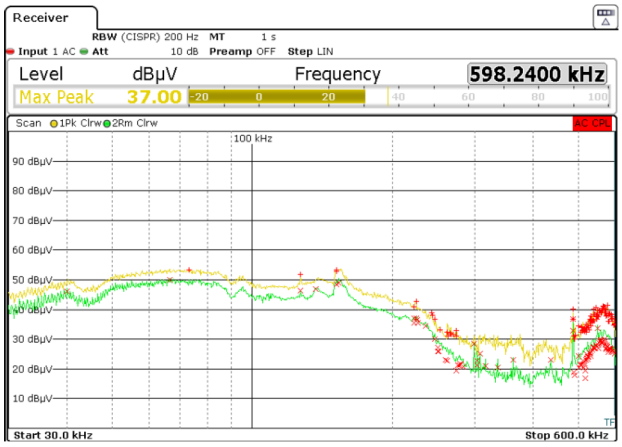


Figure 8(b). Screenshot of radio interference voltage emission recorded after refurbishment in the span of 30 kHz to 600 kHz at the north side of the converter valve station when the station is operating at its 50% capacity.

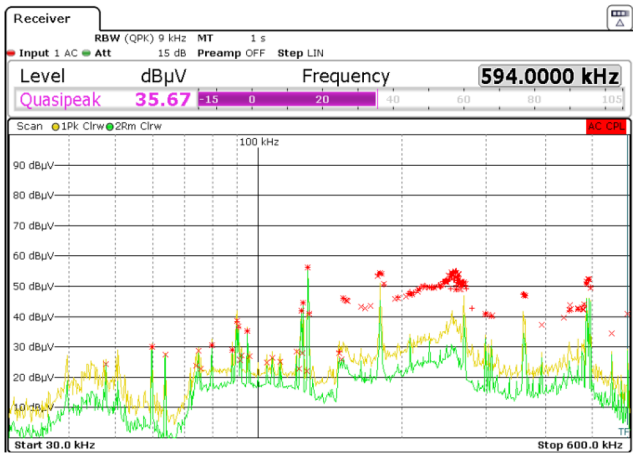


Figure 9(a). Screenshot of radio interference voltage emission recorded before refurbishment in the span of 30 kHz to 600 kHz near the converter valve station when the station is operating at 0 MW capacity.

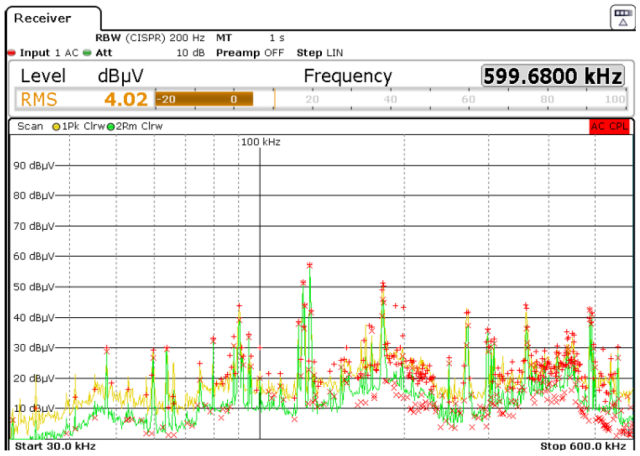


Figure 9(b). Screenshot of radio interference voltage emission recorded after refurbishment in the span of 30 kHz to 600 kHz near the converter valve station when the station is operating at 0 MW capacity.

Table 2. The highest value of RIV recorded by the EMI receiver at different load levels

Percentage of Load Injection	RIV value recorded (dBµV)	
	Before refurbishment	After refurbishment
100%	70	62
50%	58	53
10% (25 MW)	55	52
Zero %	55	52

6. Conclusions

An experimental evaluation of RIV emissions from an HVDC back-to-back converter station before and after refurbishment, based on systematic *in-situ* measurements conducted in accordance with CISPR 18-2 and CIGRE Technical Brochure 391. Measurements were performed over a wide frequency range from 30 kHz to 1 GHz at identical locations and operating conditions to ensure a fair and repeatable comparison.

The comparative analysis demonstrates that the refurbishment of the converter station resulted in a measurable reduction in RIV emissions, particularly in the lower frequency range below 1 MHz, where emissions from power electronic switching and discharge phenomena are dominant. A reduction of approximately 10 dBµV was observed near 500 kHz at the performance perimeter, accompanied by smoother spectral characteristics and a marked reduction in impulsive components. These improvements indicate effective mitigation of corona and sparking discharges as well as reduced electromagnetic emissions associated with converter valve commutation.

Measurements conducted along the transmission line at a distance of 1 km further confirm the effectiveness of the refurbishment. Post-refurbishment spectra exhibit consistently lower emission levels and reduced spectral irregularities across all measured frequency bands, demonstrating attenuation of both conducted and radiated interference components propagating from the converter station.

Near-field measurements within the performance perimeter reveal a clear dependence of RIV magnitude on converter operating conditions, with maximum emissions occurring at full-load operation. For all load conditions, post-refurbishment measurements show consistently lower RIV levels and altered spectral distributions, reflecting changes in emission mechanisms due to upgraded converter valves and enhanced valve hall electromagnetic shielding.

Overall, the results confirm that the replacement of electrically triggered thyristor valves with light-triggered thyristor valves, combined with improvements in shielding, grounding, and high-voltage hardware, leads to a significant improvement in EMC performance of ageing HVDC converter stations. The findings provide practical validation of refurbishment strategies aimed at controlling radio interference emissions and offer valuable guidance for EMC assessment and compliance verification of refurbished HVDC installations.

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8. References

1. Zhang J, Lu T, Zhang W, Xu J, Li W. Measurement and analysis of radiated disturbance characteristics of ±320 kV modular multilevel converter system. IEEE Access. 2019; 7:10028-36. https://doi.org/10.1109/ACCESS.2019.2891339
2. Rajamani P, Urukundu K, Nirgude PM. Measurement of radio interference emission around +/- 100 MVAR STATCOM valve building near 400/220 kV substation. In: 20th National Power System Conference (NPSC 2018); 2018; Tiruchirappalli, Tamil Nadu. New York: IEEE; 2018. https://doi.org/10.1109/NPSC.2018.8771779
3. Rajamani P, Aravind KA, Rajeshwara Rao K, Sandhya K, Nirgude PM. Experimental studies on radio interference of 1200 kV unipolar UHV DC transmission line. In: IEEE International Conference on High Voltage Engineering and Technology (ICHVET); 2019; Hyderabad, India. New York: IEEE; 2019. https://doi.org/10.1109/ICHVET.2019.8724321
4. Rajamani P, Devender Rao K. Impact of ambient atmospheric conditions on radio frequency interference of HVDC converter valve stations. Power Res J CPRI. 2025. https://doi.org/10.33686/pwj.v20i2.1188
5. Rajamani P, Devender Rao K, Nirgude PM. Effects of common in-service defects of different insulators on radio frequency interference emission from a 765 kV insulator string. Power Res J CPRI. 2023; 19(1):47-53. https://doi.org/10.33686/pwj.v19i1.1112
6. Sun H, Cui X, Du L. Electromagnetic interference prediction of ±800 kV UHVDC converter station. IEEE Trans Magn. 2016; 52(3):1-4. https://doi.org/10.1109/TMAG.2015.2491936
7. Wang Y, Le J, Luo H, *et al.* Prediction analysis on the interference level of radiated EMI from valve hall in the converter station of Zhalute-Qingzhou UHVDC project. Electr Meas Instrum. 2017; 54(22):11-5.
8. Xie H, Zhang X, Zhang G. Experimental study on characteristics of RF interference generated by valves and shielding effectiveness of valve hall of HVDC converter station. In: 2008 IEEE International Conference on Electric Utility Deregulation and Restructuring and Power Technologies (DRPT); 2008. p. 1961-5. https://doi.org/10.1109/DRPT.2008.4523728
9. Joint Working Group CIGRE/CIRED C4.202. Guide for measurement of radio frequency interference from HV and MV substations. Paris: CIGRE; 2009. (CIGRE Technical Brochure 391).
10. International Electrotechnical Commission. Radio interference characteristics of overhead power lines and high-voltage equipment - Part 1: Description of phenomena. Geneva: IEC; 2017. (IEC TR CISPR 18-1:2017).
11. International Electrotechnical Commission. Radio interference characteristics of overhead power lines and high-voltage equipment - Part 2: Methods of measurement and procedure for determining limits. Geneva: IEC; 2010. (IEC TR CISPR 18-2:2010).
12. Juhlin LE, Skansen J, Koppari L, Peterson E, Stenumgaard P. Measurement of radio frequency interference from high voltage substations – backgrounds and consideration for future emission requirements. In: CIGRE Session 2008; 2008 Aug; Paris. C4-102.

Author Contribution:

P.R : Conceptualization; P.R : Methodology and experimental design; P.R : Data Collection and Investigation; P.R : Writing- Original Draft Preparation ; P.R and K.D.R: Writing-Review and Editing; PR and K.D.R : Supervision and Validation.