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Analysis and Mitigation of Conducted Electromagnetic Emission in Grid Connected Adaptive Hysteresis Current Controlled Single Phase Inverter

K.Rajkumar[1], B.Karthikeyan[2] and S.Adhil[3]

[1&2]Dhanalakshmi Srinivasan Institute of Research and Technology, India.
[3]PG Scholar, A.K.T Memorial College of Engineering and Technology, India.
avk.rajkumar@yahoo.co.in

ABSTRACT

This paper presents a study of conducted EMI from grid connected single phase inverter, which is using adaptive hysteresis current control (AHCC) technique. The adaptive hysteresis current control is the widely used technique for voltage source inverters implemented for different nonlinear applications such as drive controls, active filtering and grid interfacing. But, this technique has been reported in the literature with excessive EMI emission and switching loss. Conducted EMI is presented here in the frequency domain and comply with the emission regulations in the frequency range from 150 kHz to 30MHz. In addition, this paper explicates the mitigation of EMI propagates towards the DC side of the inverter by using common mode and differential mode filters. The work carried out using MATLAB Simulink.

Keywords – Conducted EMI, Adaptive Hysteresis Current Control, Common Mode, Differential Mode.

I. INTRODUCTION

The proliferation of energy demand by both the industrial and domestic loads and diminishing conventional energy resources in parallel urges the energy industry to concentrate on distributed generating systems with alternate energy resources. The distributed generating systems are preferred due to their environmental, economical and technical advantages. Photovoltaic cells and fuel cells are noteworthy power sources for distributed generation due to their power densities and non-polluting operation [1]. In order to escalate the efficiency and curtail the cost of the systems, various transformer-less topologies were introduced [2]. The primary objective of the grid connected inverter is controlling of power flow between the ac grid and the dc source, usually renewable energy sources in distributed generation systems. The voltage source inverter (VSI) is the perfect and successful solution to interface with the utility grid due to its merits such as bidirectional power flow, low distortion, independent control of active and reactive power exchanged [3]. The control strategy used for the VSI results the effective performance of the system. The grid tied inverters usually implemented with current control methods such as hysteresis current control [4], PI control [5], sliding mode control and average current mode control (ACMC) [6]. Apart from all other current control strategies, hysteresis current control is widely used because of its simple architecture, faster dynamic response and peak current controlling ability by nature. At the same time, this technique gives variable switching frequency which causes audio interferences, increased switching losses and injection of high frequency current components. The injection of high frequency components to the source current makes the design process of filters more complex. Hence, adaptive hysteresis current control (AHCC) technique came to overcome the demerits of the conventional hysteresis current control which provides considerably constant switching frequency and variable hysteresis band [7]. The fast operating frequency of inverter switches increases voltage and current slew rates, dv/dt and di/dt, which results electromagnetic interference (EMI). The EMI causes detrimental effects on the performance of the interconnected systems by conduction and other devices in the vicinity by radiation. The vital role of solid state devices in power processing units of power delivery architecture necessitates the mitigation of EMI with suitable techniques. The EMI mitigation is achieved by modifying the power topology and/or control approaches. The fundamental mechanisms which originate the emission and a study on attenuation of EMI using common mode (CM) and differential mode (DM) filters by simulation are presented in this paper.

II. INVERTER TOPOLOGY

With the continuous development in the semiconductor technology, fast operating solid state switches such as MOSFETs and IGBTs are widely used according the power handling. Knowledge on the basic operation of the grid tied inverter is helpful for detailed the characteristic investigation of the system. The system gets input from a dc source to conceptualize PV of Fuel cell as the source of energy. The output of the inverter is connected to a local resistive load of 35Ω and the AC utility grid. The prime aim of the inverter is to convert the given dc current into alternating current correlating with the magnitude and frequency of the same in supply mains. A simple methodology to generate such sinusoidal current is shown in Figure 1.

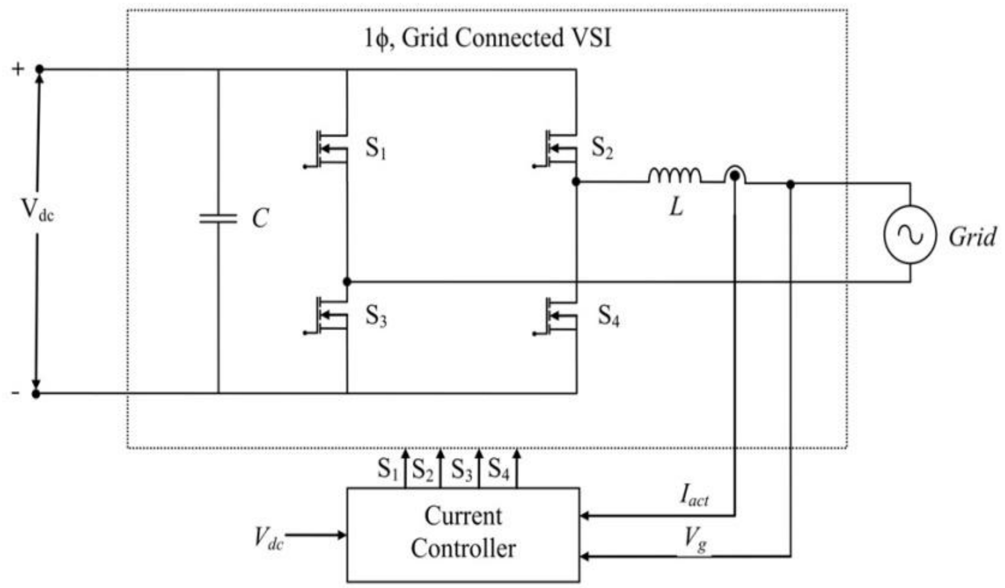

Figure 1. Basic Schematic of Current Controlled Inverter Interfaced With Utility Grid

Usually current controller is preferred in the grid connected inverters to force the output current to follow the reference current signal. The hysteresis current control (HCC) technique is the simplest current control method widely used for the inverter in DG systems due to its faster response to dynamic variations and easy implementation. The HCC computes the error between the measured current and the reference current instantaneously and the error determines the hysteresis band to generate switching pulses. This strategy controls the switches asynchronously to ramp the inductor current so as to track the determined reference current signal. But, the HCC technique is resulting variable switching frequency which cause complexity in optimizing filter circuits whereas adaptive hysteresis current control (AHCC) is introduced to optimize the switching frequency and reduce the harmonic content of the supply current [8].

III. ADAPTIVE HYSTERESIS CURRENT CONTROL

The HCC is a proven current control technique for grid interfacing voltage source inverters. It is advantageous in faster dynamic response, stable operation, accurate and easy implementation. However, the interference caused by variable switching frequency is its main drawback. The hysteresis band is always swinging around the reference signal by comparing the reference with the actual inverter current. If the difference between them is given by $\varepsilon = i_L - i_{ref}$. The switches of the inverter legs are operated when the change in inverter current i_L reaches upper and lower limits of the hysteresis band as depicted in Figure 2.

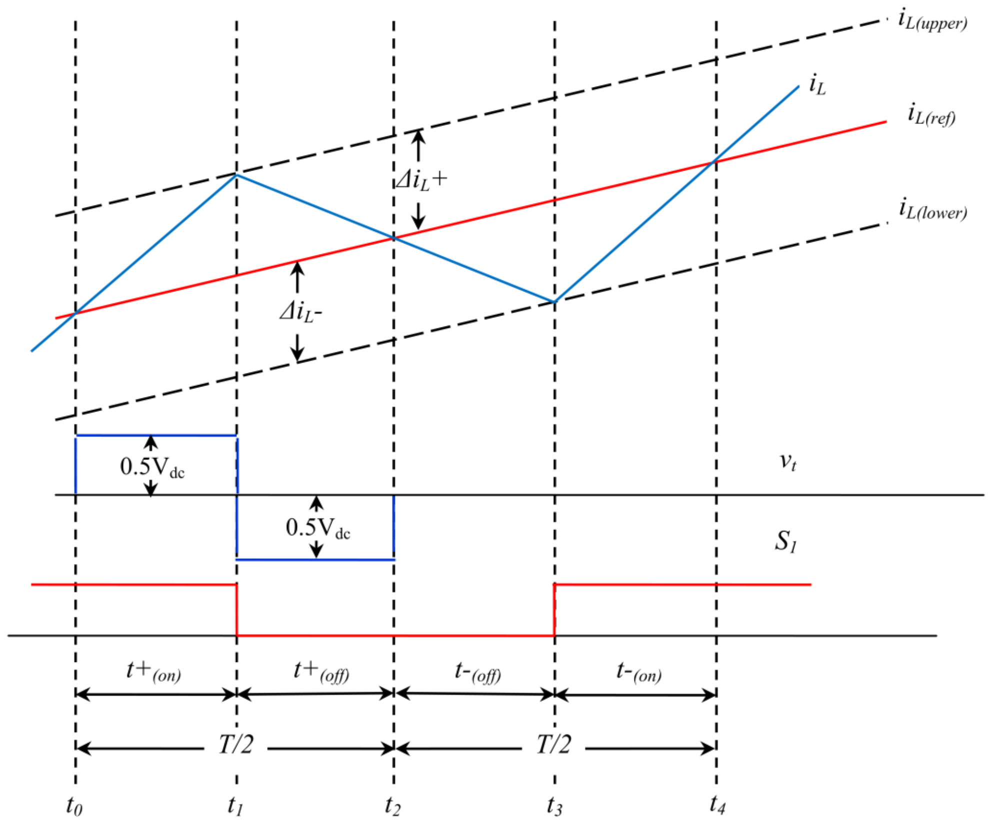

Figure 2. Concept of Adaptive Hysteresis Current Control

The aim of the controller is to make the inductor current to track the reference current. The waveform of current in Figure 2 may be divided into positive half (t_0-t_2) and negative half (t_2-t_4) in switching period T. The controller, thus, dictates '*on*' and '*off*' actions to obtain required half period of switching ($T/2$) and predicts the reference current $i_{L(ref)}$. In this way, the inverter function in bipolar PWM switching as the switches S_1 and S_4 are in a pair and S_2 and S_3 are in opposite. The change of inductor current flowing through the inductor L, for the DC link voltage V_{DC} and the instantaneous grid voltage V_g, can be defined by [8].

The hysteresis band of AHCC is determined based on the modulation frequency, grid voltage and the DC capacitor voltage. The rate of change of inductor line current decides the switching frequency and thus the constant switching frequency maintained during the entire operation.

$$\left(\frac{di_L^+}{dt}\right) = \frac{0.5V_{DC} - V_g}{L} \tag{1}$$

$$\left(\frac{di_L^-}{dt}\right) = \frac{0.5V_{DC} + V_g}{L} \tag{2}$$

It is also clear from the Figure 2, that

$$\left(\frac{di_L^+}{dt}\right)t_1 - \left(\frac{di_L^-}{dt}\right)t_1 = 2HB \tag{3}$$

$$\left(\frac{di_L^-}{dt}\right)t_2 - \left(\frac{di_L^+}{dt}\right)t_2 = -2HB \tag{4}$$

where, t_1 and t_2 are the rising and falling time respectively. Hence, the frequency is

$$f = \frac{1}{t_1 + t_2} \tag{5}$$

Substituting (3) and (4) in (5), the hysteresis band obtained as follows

$$HB = \frac{V_{DC}}{8fL} - \frac{L}{2fV_{DC}}\left(\frac{V_g(t)}{L} + \frac{di_{L\,ref}(t)}{dt}\right)^2 \tag{6}$$

The hysteresis band is thus derived with instantaneous values to maintain constant switching frequency [9].

IV. CONDUCTED EMI AND ITS MEASUREMENT

The advancements in power electronic converters extend necessary solution to the problems evolving from the power systems. However, the pulse energy conversion results EMI as by-product. The energy processes of the conversion differ in both signal power and frequency. The conversion process uses wider range of frequency from fundamental harmonics to higher harmonics of clock signals of controllers. The dynamic characteristics of the converters is directly associated with the switching frequency and their hike causes increased energy interference to range of the conducted EMI, i.e., 15kHz to 30MHz [10]. The conducted emission has two components, namely, differential mode (DM) and common mode (CM). The DM noise occurs by the flow of switching current between the power lines. The higher rate of di/dt generates higher emission with the parasitic. The CM noise is because of charging and discharging (dv/dt) cycle of the parasitic capacitances in between the lines and ground [11].

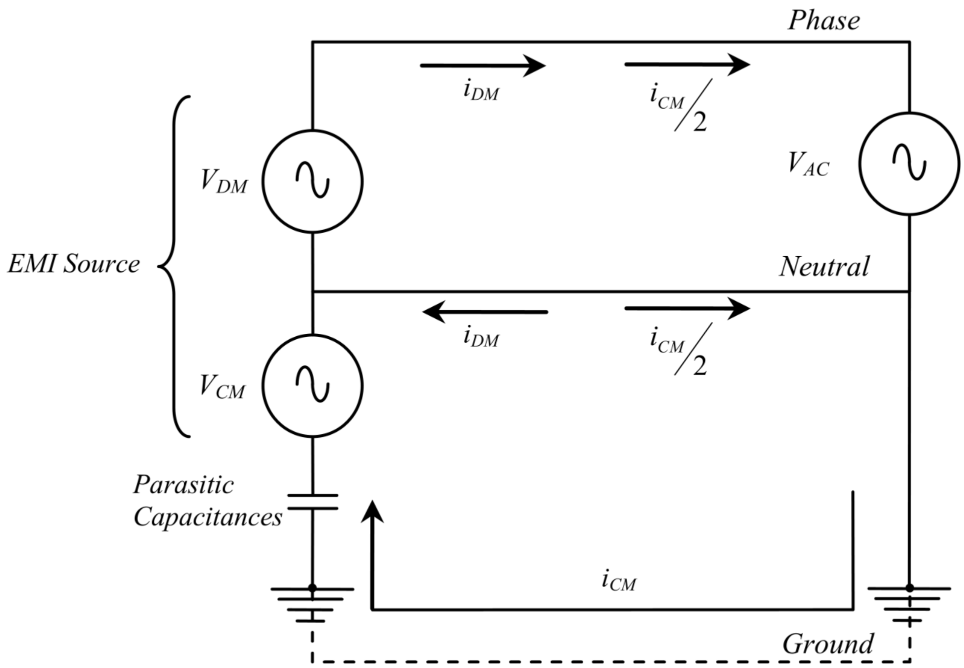

Figure 3. Propagation of Common Mode and Differential Mode EMI

Figure 3 illustrates the basic concept of common mode and differential mode EMI propagation from the source. The limits for CM and DM noises are very similar. But due to the opposite flow DM noise currents through the closely coupled conductors; its coupling with the other systems is relatively moderate. Since the CM noise currents flow through the separated and larger conducting paths, it may behave as an effective antenna and requires greater attention.

The EMI measurement includes the measurement using standardised equipments and comparison of the result obtained with the limits recommended according to the equipment under test (EUT). The conducted emission is generally interpreted by the voltage appear at the input of the test receiver. In order to convert the physical quantities such as electromagnetic field, etc. into voltage line impedance stabilization network (LISN) is used. However, EMI measurement requires the fundamental knowledge on the applied measuring technique. The LISN assures repetitive, stable and standardised measuring conditions.

Even though the worldwide community concerns on electromagnetic pollution, Europe has taken a lead in standardizing interference phenomena which has resulted in the compulsory introduction of EMC standards from the year 1996. The standards are fundamentally grouped to direct (i) Emission (Conducted and Radiated) and (ii) Immunity (Conducted and Radiated) [12]. The standards used widely are Comite International Special des Perturbations and Radioelectrique (CISPR), Federal Communications Commission (FCC), British Standards (BS), Verband Deutscher Elektrotechniker(VDE) and Voluntary Control Council for Interference (VCCI) [13]. In this paper, the conducted EMI measured as per CISPR 22 in which Class A is defined for the devices used in commercial, industrial, or business domains and Class B is defined for residential environments.

V. MITIGATION OF THE CONDUCTED EMI

In this paper, a simple technique for the design of EMI filter in the frequency band of 150 kHz to 30MHz is proposed to mitigate the generated EMI noises propagates into DC side of the inverter. The main aim of this work is to minimize the components required and the cost with reduced complexity. Figure.4 shows the filter structure including DM and CM filter at the input side of the inverter. The filter exhibits higher insertion losses when the interface source and interface sink are mismatched. The low frequency portion, 150 kHz to 1MHz, contains both DM and CM noises. The DM can be attenuated by DM filter and the low frequency components of emission can be filtered by the non-ideal leakage inductance of CM filter. Meanwhile, a minimum portion of CM noise can also be attenuated by the symmetrical inductances of the DM filter.

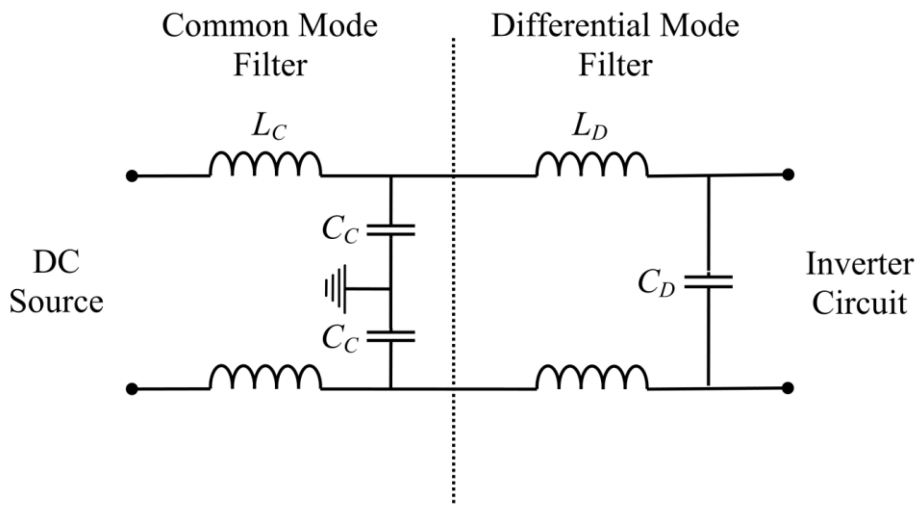

Figure.4. Structure of typical DM and CM EMI Filter

A. Design of CM Noise Filter

Usually the CM currents flow through the parasitic capacitances during transient operation. The predicting the value of CM current is practically tedious and hence the designing of CM filter is also difficult [14]. The filter impedance is $\left|Z_{sf}\right| = 2\pi f_0 L_C$ where, f_0 is the lower limit of the frequency range which is 150kHz as per CISPR 22. Then, the inductance L_C has been chosen as, $L_C \rangle \frac{\left|Z_{\sin k}\right|}{2\pi f_0}$, where $|Z_{sink}|$ is the sink impedance. The L_C and C_C decides the cut-off frequency, $f_{cut} = \frac{1}{2\pi\sqrt{\left(L_C C_C / 2\right)}}$.

B. Design of DM Noise Filter

The CM filter inductance almost short-circuits the DM noise currents and also the leakage inductance of the CM filter helps to mitigate considerable amount of DM noise. Since the inverter acts as the source of harmonics, the DM filter is used to eliminate the DC ripple from the inverter side in to possibly lower than the range recommended by the standard. The DC component passes the DM filter easily but the harmonic is attenuated to greater extent. In order to block the double fundamental frequency, the cut-off frequency is set as f_{cut}=100Hz. Then, the inductance L_C has been chosen as, $L_D \rangle \frac{\left|Z_{\sin k}\right|}{2\pi f_0}$, where $|Z_{sink}|$ is the sink impedance. The L_D and C_D decides the cut-off frequency, $f_{cut} = \frac{1}{2\pi\sqrt{L_C C_D}}$.

The components of input filters must be selected so as to ensure that there is no degradation of performance and better level of noise elimination by both the filters [15].

VI. EMISSION RESULTS

The simulation is to investigate the total conducted EMI emitted through the DC line and its reduction after introducing filters. The work carried out using MATLAB. The inverter model is connected to the local load of 50Ω and the utility grid. LISN is placed on the DC side of the inverter. The conducted emission measurement was taken as per CISPR22. The widely used CM and DM EMI filter topology used to mitigate conducted emission to input side of the inverter. Figure 5 shows the total conducted emission without filter. This result shows the highest peak of 107dBµV at 5MHz and average of 60dBµV across the spectrum (150 kHz-30MHz) can be observed.

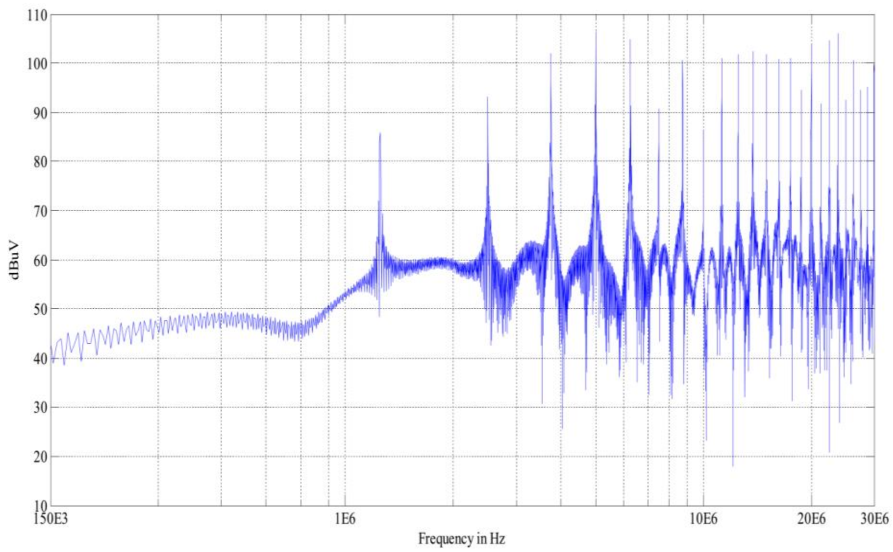

Figure 5. Total Conducted EMI Spectrum without Filters

Figure 6 shows the conducted emission spectrum measured after incorporating the CM and DM filters at the DC side of the inverter module. The average of 45dBµV can be observed throughout the frequency spectrum and the dominant peak recorded is 75dBµV at around 3.2MHz.

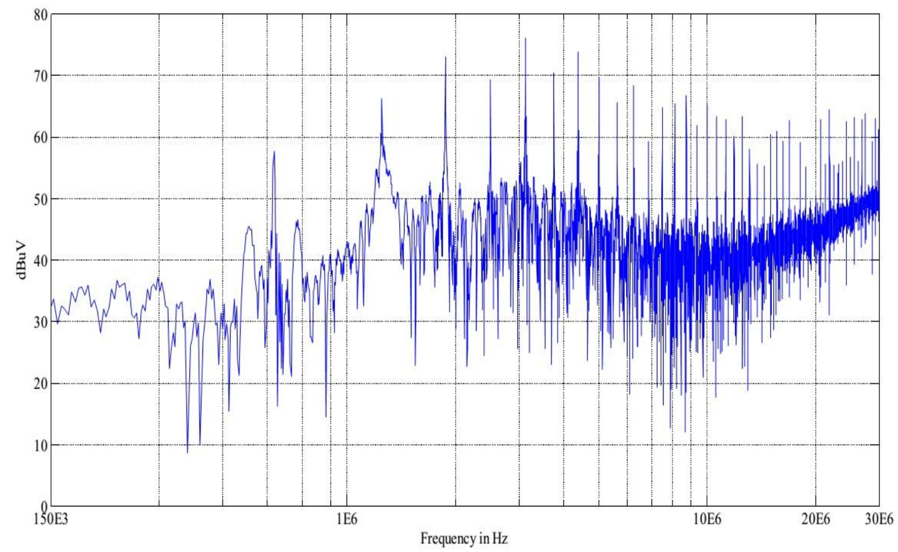

Figure 6. Total Conducted EMI Spectrum with Filters

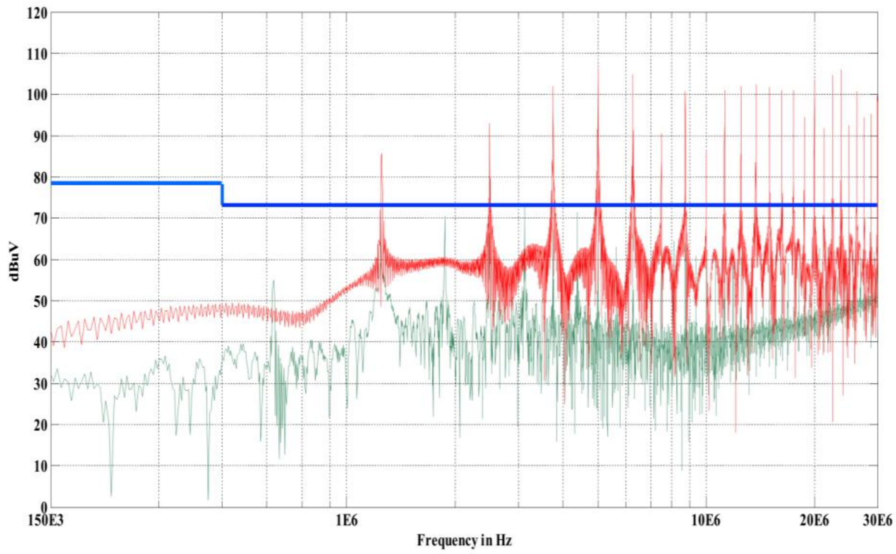

Figure 7. Comparison of Total Conducted EMI with and without filter

Figure 7 clearly depicts a comparison of conducted EMI spectra measured at input side of the inverter with and without EMI filter. The average level of emission recorded in both the cases is below the limit recommended by the CISPR 22. But, the dominant peak recorded after using EMI filter is just meeting the limit once at 3.2MHz wherein the spectrum recorded without filter the peaks often crosses the limit.

VII. CONCLUSION

This paper has provided the detailed study of electromagnetic emission from the grid-tied AHCC inverter and its reduction using generally implemented CM and DM filters. Use of passive filters is a good choice in cost effective and simple design. Since the series inductive impedance of the filter id proportional to the frequency, it is desirable at higher frequencies. However, their performance is highly source dependent. The results indicate that the designed combined CM and DM noise filters are able to attenuate total conducted emission much below the limits allowed by the CISPR 22 Class A. The proposed filters with the AHCC inverter can undoubtedly mitigate the conducted emission without much design cost. However, the proposed EMI filter does not take into account the parasitic components of the entire design in this analysis.

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