International Journal of Applied Engineering Research
ISSN 0973-4562 Volume 10, Number 9 (2015) pp. 23523-23534
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An Overview Of Conducted EMI And Its Mitigation In Photovoltaic Systems

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ABSTRACT

This review paper concentrates on the issues related to the electromagnetic interferences (EMI) generated by the switching devices used in the power processing circuits of isolated or utility connected photovoltaic (PV) energy conversion systems. The EMI generated due to the fast switching devices are normally classified into conducted EMI (150kHz-30MHz) and radiated EMI (30MHz-1GHz). The conducted EMI is further categorized as common mode (CM) and differential mode (DM). This paper also presents an overview of mitigation techniques and the possibly implemented techniques in the EMI issues of PV Systems.

Keywords – EMI, Phtovoltaic, LISN, EMI Mitigation.

I. INTRODUCTION

The rapid depletion of fossil fuels used for energy generation and serious environmental pollution due to their usage paved the way for alternate sources of energy to meet out the increased demands in future. Among all other renewable energy sources, solar might be the appropriate choice. However, the ubiquitous solar energy needs to be harnessed according to the requirement of the applications. This can be achieved by a set of electronic circuitry from the electrical energy produced at the solar cells. This circuitry arrangement processes the steps from the available raw energy to the usable electrical supply at the consumer end.

But, the energy conversion system produces electromagnetic pollution or interference [1] [2], either by conduction or by radiation. Hence, it is essential to concentrate in avoiding or reducing the interferences into the level by which the other connected or nearby equipments can function normally. EMI mitigation techniques are commonly used in power electronic systems to satisfy the relevant standards. EMC considerations at the design level reduce the cost [3].

The literature survey shows that there were number of researches on the EMI/EMC of AC drives [5] and switched mode power supplies [3] [4]. However, it is not found much on the PV inverters both in isolated or grid connected system. A few papers pointed out the EMI issues either being conducted or radiated. It is found that the DC side wiring of the low power PV plant acts as an antenna and couples with the external EM fields[6] [7][8]. Mostly the inverters used in PV systems are incorporated with EMI filters to minimize EMI noise originated from the switches and propagates to the utility grid or connected load in standalone systems. Hence most of the noise generated during switching is diverted towards the DC side [1].

This paper starts with an introduction on the conducted EMI and standards and measurements in Section II. This is followed by the different mitigation techniques presented in Section III. In Section IV, different remedial approaches addressed in PV systems are presented. Finally, summary and conclusions are presented in Section V.

II. CONDUCTED ELECTROMAGNETIC INTERFERENCE (EMI) AND RELEVANT STANDARDS AND MEASUREMENTS.

A. Conducted EMI:

The conducted EMI is propagating in two modes; namely common mode (asymmetrical) and differential mode (symmetrical). Differential mode means the normal transfer of energy down the line. In other words, it flows just like normal power in the line energy. Common mode means a voltage impressed across both, or all, lines. This voltage is between all these lines and ground. In this unbalanced case, differential mode and common mode act the same-between line and ground.

The common mode noise originates from either electric or magnetic sources. This EMI is electrically originated whereas the conductor with higher *dv/dt* has a considerable parasitic capacitance to ground. The common mode EMI is magnetically generated due to higher *di/dt* in the closed loop and by considerable mutual coupling to a set of nearby conductors. The differential mode EMI is resulting from the switching processes like the entire or a part of a pulsating switching current flow in the conductor.

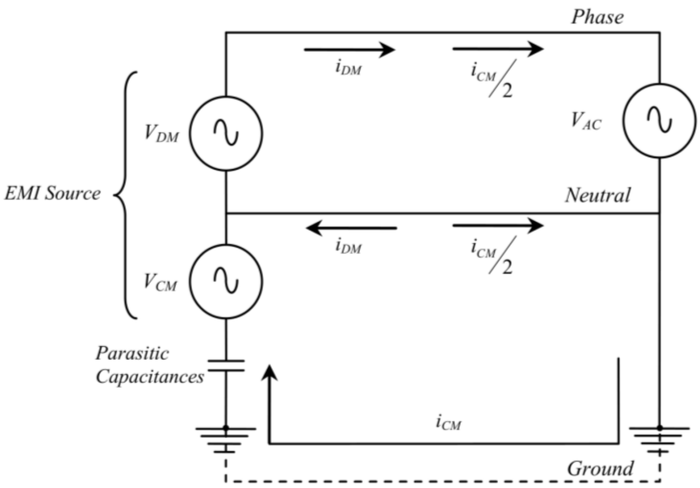

Fig. 1 Propagation path of Conducted EMI

B. Standards for EMI in PV System

The EMC awareness is growing on a worldwide scale, due to rapid increase of 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. Basically the standards are grouped as follows: i) Emission (Conducted and Radiated) and ii) Immunity (Conducted and Radiated). IEC further classifies the standards in to three categories: a) Basic Standards (Sets down the basic requirements for interference source oriented test), b) Generic Standards (Specifies a set of minimum requirements and tests for all appliances and equipment which are used in a given environment, e.g., domestic, industrial etc.) and c) Product and Product Family Standards (Established by each committee responsible for certain product categories).

For the power supplies, some commercial EMI standards are available and specify the acceptable level of net line noises. The most widely accepted commercial standards are due to Comite International Special des Perturbations and Radioelectrique or International Special Committee on Radio Interference (CISPR), Federal Communications Commission (FCC), British Standards (BS), Verband Deutscher Elektrotechniker(VDE) and Voluntary Control Council for Interference (VCCI) [9].

Fig.2 shows the conducted emission limits as per the widely used CISPR 22. In CISPR 22, Class A defined for the devices used in commercial, industrial, or business domains and Class B defined for residential environments [10].

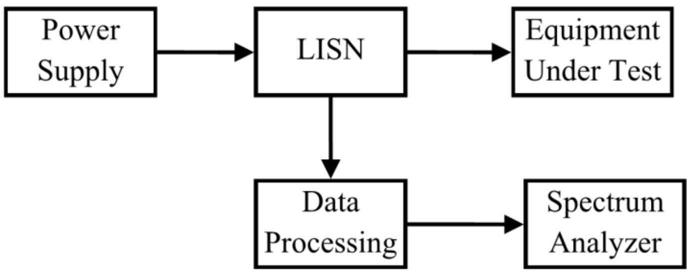

Fig. 5 EMI Measurement System

Since there is no specific category for PV devices, there are no particular EMC standards available for photovoltaic systems right now. Even though there is no clear idea under which condition the PV system can be categorized, i.e., as a single entity in laboratory or at the installation with the real environment, a number of attempts come up with available power supply standards.

According to the Directive 2004/108/EC of European Parliament and of the Council, "Apparatus" is defined as the commercially available single functional unit intended for the end user and liable to generate EM disturbance or liable to be affected by such disturbance. It also defines "Fixed Installation" as a particular combination of numerous types of apparatus and, where applicable, other devices, are assembled, installed and intended to be used permanently at a desired location [11]. Hence the grid connected PV systems are considered as the fixed installation when it is fixed to feed power to the utility grid.

As per the above directive, the applicable standards for the fixed installations like grid interfaced PV system are normally generic standards. Hence EN61000-6-2 is for Immunity and EN61000-6-4 is for emissions [12]. These standards describe the actual test method to be done. In standalone application, the PV system is considered as apparatus and the entire system must comply with the EMC.

Emission regulations are mostly based on CISPR standards pertaining to control and measurements interference in the frequency range of 9 kHz to 18 GHz.

C. Measurement of EMI

The typical EMI measurement system requires Line Impedance Stabilizing Network (LISN), noise separator, spectrum analyzer and computer to interface the spectrum analyzer for data processing. LISN is used to provide stable power line impedance for repeatable EMI measurement. The standard components inside the LISN are the inductance offers very small impedance and capacitor offer open circuit for 50Hz. For higher frequencies, however, the inductance opens the circuit and the capacitance shorts the circuit. Thus the high frequency noise current produced by switching is coupled into the 50Ω resistors. The voltage appears across 50Ω resistors is measured as conducted EMI due to both CM and DM currents as mentioned in Fig.3 [3].

LISN captures the conducted emission. The noise separator is used to separate the CM and the DM noises and feed to the spectrum analyzer. Then the data is given into the computer for further analysis.

EMI emission from the equipment under test is obtained by the L and N of the LISN. The emission captured has the following relationships:

Positive Line EMI Voltage, $V_L = V_{CM} + \frac{V_{DM}}{2}$ (1)

Negative Line EMI Voltage, $V_N = V_{CM} - \frac{V_{DM}}{2}$ (2)

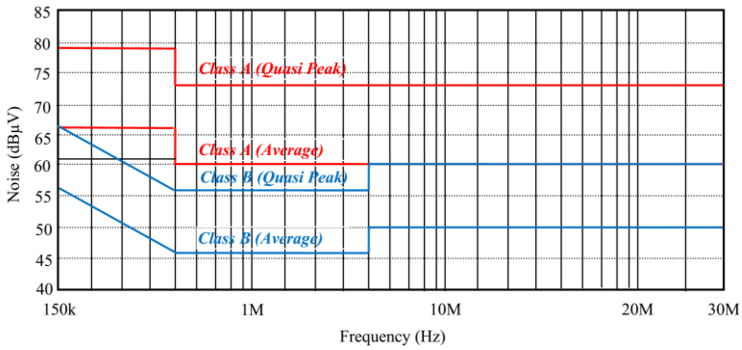

Fig. 2. Allowable limits of conducted emissions as per CISPR 22

The above two signals mentioned in (1) and (2) fed to the noise separator in which the inbuilt features can separate the noise into CM and DM. Two channels of DSO can also be used to separate the noises in real time measurements instead of noise separator as follows:

$$V_{CM} = \frac{V_L + V_N}{2} \tag{3}$$

$$V_{DM} = \frac{V_L - V_N}{2} \tag{4}$$

The noise spectra is usually digitalized for signal processing to correct the errors and the analysis of peak, rms, average and quasi peak values of EMI signals can be performed. A current probe with a very broad frequency band can be used [13].

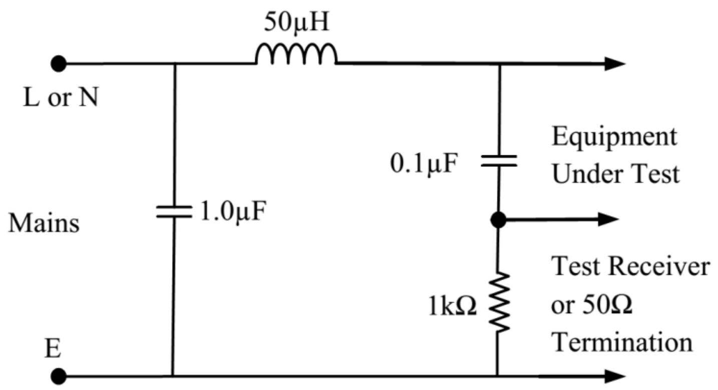

Fig. 3 Standard LISN (CISPR 22)

III. EMI MITIGATION

EMI mitigation techniques usually require modification in the power topology or control approaches [3]. The techniques are mainly classified into two categories: (a) techniques in power section and (b) techniques used in control sections. At the same time, popularly used grounding and shielding techniques can be used in both the cases.

Two concepts implemented to reduce EMI in control strategy are (i) variations in the frequency of switching and (ii) gate circuit improvement. By varying the switching frequency, spreading of EMI spectrum is achieved and as a result, EMI level is reduced [14]. The widely used techniques under this concepts are randomized modulation, frequency modulation, chaos control, sigma delta etc,. These techniques improve the EMC and leads to higher THD and greater complexity [15]. The gate circuit improvement techniques using active and passive components [16] may increase the switching losses.

Snubbers are used to reduce the EMI by reducing *di/dt* and *dv/dt* and are classified as active and passive snubbers. Snubbers decrease EMI and result reduced efficiency due to increased power dissipation. Later active lossless snubbers and regenerative snubbers have been introduced. Active clamp circuits are introduced to minimize the voltage spike of the main switch. The introduced active clamp concept decreases EMI by eliminating ringing in off-time mode of the switch [17].

EMI filter is a general solution to satisfy the standards in power converters. Many filtering concepts based on active and passive approaches have been introduced to mitigate conducted EMI. In order to discriminate CM and DM noises, the filter topology presents separate equivalent attenuation paths for each noise. Passive EMI filters are bulky LC low pass filters and reduce the high frequency noises. These filters increase the cost and size of the converters [4]. Using active filter topology, the low frequency attenuation can be improved. It uses a current transformer to sense the noise current and injects the compensation back to the line through an RC branch connected to a comparator [18].

Soft switching has been addressed in literature to reduce EMI by reducing *di/dt* and *dv/dt*. The soft switching can reduce EMI in some cases but not satisfactory in all the cases. This concept has also been compared with hard switching in many works. It is noted that the practical implementation of soft switching is not much easier due to increased number of elements and leads to extra resonances. This problem urges to find other suitable EMI attenuation strategies [19]. It is also enumerated that the hard switching with snubber circuits are performed well than the soft switching in noise reduction. The elements incorporated with the soft switching concept may lead to more parasitic and need attention in EMI aspect.

Interleaving concepts are mostly used in high power converters. This concept is paralleling the switches with an equal switching frequency while switching times are ordered in sequence. Interleaving topology reduces the current ripple and hence the EMI, specifically in DM. This interleaving concept is also advantageous by minimizing the number of magnetic components, reducing the device stress and decreasing the output capacitor ripple. The size and cost of EMI filter can also be reduced by minimizing the ripple. The disadvantage of this topology is the increased components and layout space [20].

Parasitic cancellation approach is used to minimize the EMI from its source. In this concept, introduction of auxiliary circuits to reduce reverse recovery current, negative capacitance method to cancel parasitic of inductors and transformers, Faraday shield to reduce inter winding capacitance were considered [21].

Noise compensation can be achieved by introducing an auxiliary circuit in power section. This concept is mainly applied to reduce common mode EMI by reducing equivalent earth leakage current [22]. Active and passive compensation techniques can be introduced in which active technique is more flexible and expensive and passive is simple and cost effective.

Balance approach can be accomplished by topology modification to cancel one term of CM noise by another term, instead of minimizing. Balancing can be attained by a symmetric topology or by balance condition of a Wheatstone bridge. The symmetric topology makes the drain and source voltages equal and 180^o displaced to reduce CM noise through the earth. However, the extra diode involved increases the conduction loss [23]. The parasitic capacitances should also be equalized to eliminate the noise current to the earth.

PCB Layout and placement can minimize both conducted and radiated EMI. In recent days, CAD aided PCB designs help the designers to deal with EMC by trial and error methods. Traces with the high voltage transients, like the traces connected with MOSFET drains emit a strong electric filed in power converters and cause electric field coupling. PCB layouts are optimized by separating the drain and input lines in larger extent. The placement of switch and transformers are also modified to decrease length of the trace and larger separation. It is experimentally proved that the optimized layout has considerably reduced the CM noise. Shielding of the drain tracks with two constant voltage tracks and reduced di/dt in a PFC boost converter yields reduced radiated EMI [24].

Ferrite beads are used to minimize unwanted transients and noise emission in power board. Ferrite beads offers higher impedance to high frequency noises whereas lower impedance to lower operating frequency [9]. By suitably selecting and placing the ferrite beads, a remarkable noise reduction can be attained. It is advised to place ferrite beads in series with the power traces for better attenuation of noises.

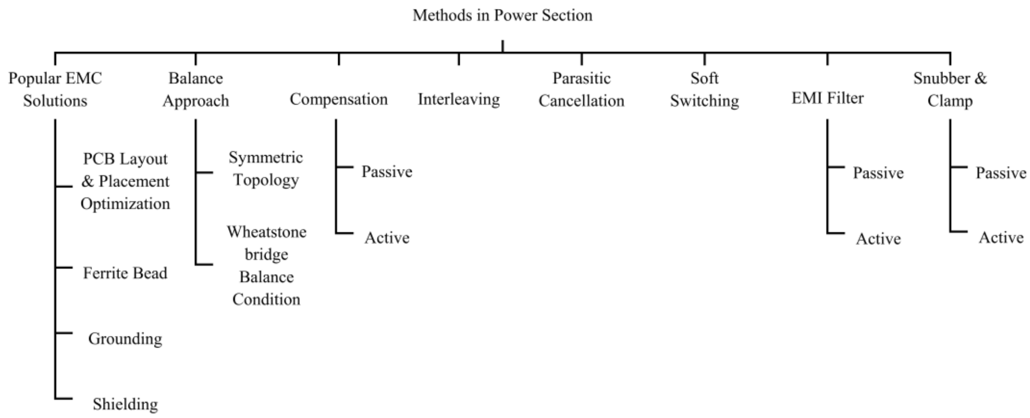

Fig.4. EMI Mitigation techniques applied to power section.

IV. IMPLEMENTATIONS IN PV SYSTEMS

Many research works have been investigated the EMC performance of drives and switched mode power supplies. But, not much literature can be found for EMC performance of the PV inverters in grid connected or standalone application.

In [25], the chaotic PWM method has been implemented to suppress the EMI at switching itself. Chaotic switching process greatly minimizes the chance of concentration of noise at the multiples of central frequency. Hence, the spreading of noise in wider frequency reduces the EMI. It is also advised to combine the advantages of both EMI filters and chaotic PWM switching to obtain effective reduction of noise. The switching frequency modulation (SFM) has been applied in [26] to reduce EMI. This technique is derived from spread spectrum clock generation (SSCG) techniques. The PWM spread spectrum control can be mentioned as, $f=f_s+\Delta f$, where, f_s is the reference frequency of the switch; Δf is the additional spread spectrum signal frequency which changes according to the characteristics of spread spectrum signal. Hence, it is clear that the PWM spreading control is depending on the control of Δf. The PWM control is the chaotic spreading when Δf is the chaotic signal. Chaotic control is a non-linear control in power electronics and it can generate non-harmonic switching spectrum when the parameters of the controllers are correctly chosen. Simplicity is its advantage and the drawback is that the designer must clearly observe the performance of the circuit and parameter variations to ensure the spread spectrum operation.

Use of the isolation transformer in addition to the EMI filters is analyzed in [27]. Common mode filtering performed well in EMI attenuation even in absence of isolation transformers. But the non-isolated configurations increases losses due to large common mode current flow through the filter and its energy dissipation. By providing isolation transformer, low capacitance is constituted in series common mode source. This can avoid low level common mode currents and the losses. The attenuation characteristics of EMI filter differs from single converter system to multi-converter systems because of variation in cut-off frequencies of the filters in multi-converter systems. Therefore, the effective attenuation of the conducted EMI cannot be accomplished [28]. By solving common mode equivalent circuit, the attenuation characteristics of the system can be determined; but the calculation becomes complex as the number of parallel converter increases.

The widely used 3 level single phase PWM is compared with 2 level single phase PWM in single phase H bridge PV inverters in [29]. The effect of transformer shielding on EMC performance has also been described. The 2 level PWM synchronizes two diagonal switches of the inverter and avoids common mode voltage generated at source side in the ideal case. But in practice, the chopped voltage is twice that of with 3 level PWM; hence CM noise arises by the higher ripples in voltage and currents. The 2 level modulation can reduce EMI emissions owing to voltage transients at switching for the cost of higher harmonic losses. Shielding controls the high frequency coupling between the primary and secondary by controlling stray capacitance. The values of stray capacitance optimize the CM noise reduction. The use of transformer shielding is therefore satisfactorily improves the EMC performance. Transformer shielding is effective but costly and may not possible to accomplish in all the case. In this instance, shunt capacitance on primary side and/or on secondary side can be connected to form voltage divider with the filter inductance so as to reduce high frequency voltage components.

V. CONCLUSION

The grid integrated or standalone photovoltaic system has to be designed properly in such a way that the emissions originated by the system are within the permissible limits set by the appropriate standards. This will confirm that the PV systems do not affect the functioning of nearby equipments. The EMI reduction at source is more desirable than attenuation along the path of travel, as the earlier can even reduce the possibility of radiation too. Prediction of EMI by simulation and analysis will be useful to the designer to predetermine the amount of noise emission and to trace the suitable place for improvements. The EMI mitigation techniques reported in the literature were categorized in to various sections. The selection of mitigation techniques is not simple but depends on different factors, like application, topology used, cost and volume of the system. Individual or combined techniques may yield better result in attenuation of the conducted noise.

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