ESTIMATION AND MITIGATION OF DIFFERENTAIL MODE NOISE USING EMI FILTERS FOR POWER CONVERTERS

PATHALA VENKATA SAI CHARISHMA[1], PAPPU.V. Y JAYASREE[2]

[1,2]Department of EECE, Gandhi Institute of Technology and Management, Deemed to be University, Visakhapatnam, India, 530045.
[1]cpathala@gitam.in, [2]jpappu@gitam.com

ABSTRACT

The Electro Magnetic Interference [EMI] problem occurs in electronic devices due to change in switching speed of electronic components. The interference occurs in electronic devices produces noise inside the circuit, the noise decreases the performance of the system and also destroy the components inside the circuit. The noise generated by the equipment has some specific limits as per CISPR STD, so the design of filter has to reduce the noise as per CISPR limits. In this paper Single Ended Primary Inductor Converter [SEPIC] acts as a noise source which is a DC-DC power converter used in many digital applications. The designing of EMI filter for elimination of differential mode noise generated by the power converter by using MULTISIM software and MATLAB. The filter design is made up of passive components called inductors and capacitors. The total setup for estimation of noise from equipment and mitigation of noise with filter consists of Line Impedance Stabilization Network [LISN], Equipment [SEPIC], Noise Separator [Active and Passive noise separators], Power Line filter, PI filter. The LISN is used to produce the constant output impedance in the circuit. The noise generated by the power converter is measured by the noise separators used in the measurement setup. The noise obtained at the output of active and passive noise separator is same with value of 119 dBμV. So, the filter is designed to reduce the noise generated inside the circuit the noise at the output of power line filter is 51.5 dBμV and with PI filter is 52.2 dBμV. The comparison between the filters and calculation of noise from equipment using two type of noise separators are shown in this paper.

Keywords-*Electro Magnetic Interference [EMI], Single Ended Primary Inductor Converter [SEPIC], Power Converters, Line Impedance Stabilization Network [LISN], Noise Separator, Power Line Filter, PI Filter.*

1. INTRODUCTION

The operation of electronic devices stops working or poorly works due to Electro Magnetic Interference [EMI] problem in the circuit [1]. The interference in the circuit is due to the noise caused by the external electromagnetic environment [2],[3]. The generation of EMI is done in two ways Natural and Manmade source [4]. The occurrence of EMI in two modes radiated mode and conducted mode. The power converters are used in many applications for maximizing the performance and enhancing power density are the major source of EMI [5]-[7]. Different techniques are used for calculation of EMI noise from the power converter [8]-[10]. Different EMI standards specify the maximum limit of interference occurs in the electronic system. Mitigation of interference in the electronic device can be reduced by using EMI filter.

Different type of power converters is used in many applications for generation of noise inside the circuit. Diode bridge Boost power converter is used and reduction of noise is done by 2 stage differential mode EMI filter [11]. The active EMI filter is used for elimination of noise from switched mode power converter circuit act as noise source [12]. The LC filter and PI filter are used for reduction of noise in AC-DC power converters [13], [14]. The power converters are of two types DC-DC power converter and AC-DC power converter. BOOST, BUCK, SEPIC, BUCK-BOOST are the different type of power converter used in DC-DC application. In the

ISSN: 1992-8645 www.jatit.org E-ISSN: 1817-3195

above literature the active EMI filters are used with n stages for AC-DC power converters. The switched mode power converter is act as a DC-DC power converter and active and passive EMI filter with multiple stages are consider for elimination of noise generated by these power converters [15].

In this paper the DC-DC power converters called Boost and Buck converter is consider as a noise source in the measurement setup. The DC-DC power converters are used in many applications like mobile phones, laptops. It is used to stabilize the voltage inside the circuit act as a voltage regulator, so the power converters used in this paper is not for single application. The passive EMI filter with single stage is taken for reduction of noise as per CISPR 22 STD. The filter characteristics depend upon the switching frequency and input and output impedance of the circuit. The noise separator used for measurement of noise generated by the power converter is differential mode noise separator which eliminates common mode noise and produces the differential mode noise. The differential mode EMI filter is also considered for elimination of noise.

The noise generated in conducted mode is classified into two type of noises, Common mode [CM] noise and Differential mode [DM] noise [16]-[17]. In common mode noise current conducts in same path for both power conductors [V_P, V_N] and return via ground conductor [V_g]. In differential mode noise flows in one conductor and return via another conductor.
The common mode noise is calculated by using the equation

$$V_{CM} = \frac{V_P + V_N}{2} \quad (1)$$

The Differential mode noise is calculated by using the equation

$$V_{DM} = \frac{V_P - V_N}{2} \quad (2)$$

V_P = Phase voltage, V_g = Ground voltage, V_N = Neutral voltage

The frequently used EMC standard for IT applications is CISPR 22. This standard has maximum frequency for conducted mode is 30MHz and for radiated mode is 100MHz. If the emissions obtained from equipment are increased than the limits specified by the CISPR standard then the designed EMI filter can minimize the interference generated in the equipment [18].

Table 1: CISPR 22 Limits For Conducted Emission

Frequency Range (MHz)	Class A devices dB(µV)	Class B devices dB(µV)
0.15-0.5	79	(66-56)
0.5-30	73	60

In this paper the schematic diagram for conducted emissions set up was designed in MULTISIM software. The suitable EMI filter was designed for the equipment under test and validation of results are done in simulation tool called MATLAB.

1.1 Methodology

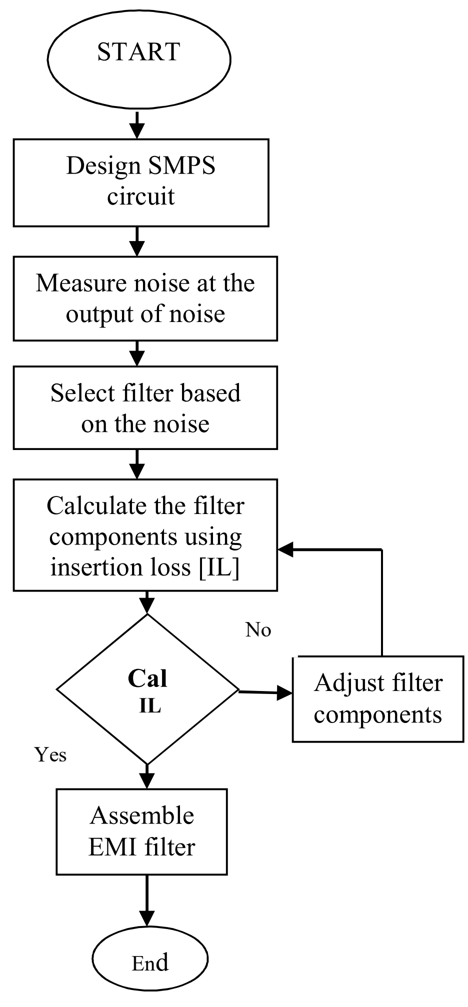

Figure 1: Flow Chart of The Proposed System

Journal of Theoretical and Applied Information Technology
15th May 2023. Vol.101. No 9

ISSN: 1992-8645 www.jatit.org E-ISSN: 1817-3195

2. MEASUREMENTS

2.1 Impedance Measurement

The conducted EMI limit can be achieved by designing an EMI filter with consideration of various parameters to increase the performance of the filter, the parameters like noise source impedance and termination impedance over a frequency range. The noise termination is calculated at the output of the LISN which gives constant 50 ohms output impedance over a desired frequency. Noise source impedance is calculated by removing LISN and measurement is done at the output of equipment, the impedance increases linearly with frequency range.

2.2 Noise Measurement

The measurement setup for calculation of differential mode noise is shown in be Fig.2. The measurement setup consists of DC power supply, LISN, equipment [SEPIC power converter] acts as a noise source due to switching elements in the circuit, Noise separator [Active noise separator, differential mode noise separator]. The noise separators are used for measurement of noise in the equipment [19].

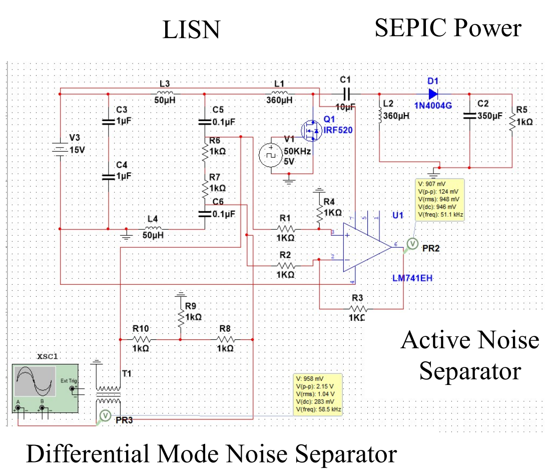

Figure 2: Differential Mode [DM] Noise Measurement Setup in MULTISIM Software

The active noise separator circuit is op amp subtractor circuit which gives differential mode noise and eliminates the common mode noise. The op amp adder circuit gives the common mode noise and eliminates the differential mode noise. The differential mode noise separator gives the differential mode noise at the output of the noise separator.

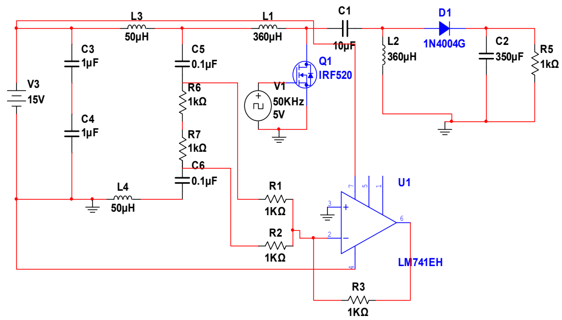

Figure 3: Differential Mode [DM] noise measurement setup with Active Noise Separator in MULTISIM software

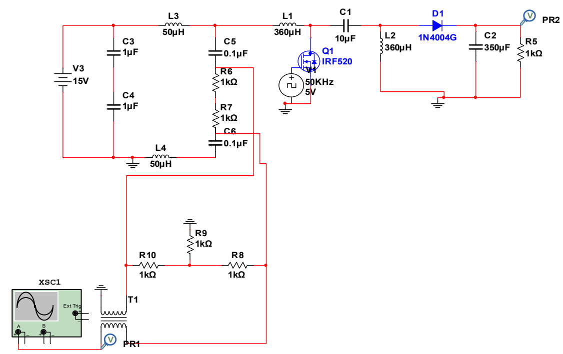

Figure 4: Differential Mode [DM] Noise Measurement Setup with Differential Mode Noise Separator In MULTISIM Software

The equipment is supplied by DC power supply of 15V through LISN, the LISN generates the constant output power with output impedance of 50 ohms to the SEPIC power converter. The equipment acts as a noise source due to diodes, transistors. The noise generated from this equipment is calculated by connecting noise separator to the LISN when equipment is connected to LISN. The noise separators used in this measurement setup is active noise separator and differential mode noise separator which eliminates common mode noise and gives the differential mode noise at the output of the noise separator.

The noise at the output of the active noise separator is 907 mV, for comparison of noise level with CISPR 22 standard the noise has to be converted into dBµV by using the equation 3, the differential mode noise at the output of active noise separator is 119.2 dBµV.

The noise obtained at the output of the differential mode noise separator is 119.6 dBµV. Both the noise separator calculates the same noise from the

ISSN: 1992-8645 www.jatit.org E-ISSN: 1817-3195

equipment. The observed noise is exceeding the limits of EMI standard are shown in fig 5.

$$1dB_{\mu V} = 20\ log_{10}[\mu V] \quad (3)$$

Table 2: The Noise Levels at The Output of Noise Separator

Noise Separator	Noise Value [mV]	Noise Value[dBμV]
Active Noise Separator	907	119.2
Differential Mode Noise Separator	956	119.6

The noise is reduced and make the equipment compatible with CISPR limits is done by designing an EMI filter. The design of EMI filter should consider an insertion loss of minimum value, it can be calculated by using the equation 4

$$IL_{DM} = V_{DM}[\text{ dB}\mu\text{V}] - V_{LIMIT}[\text{ dB}\mu\text{V}] \quad (4)$$

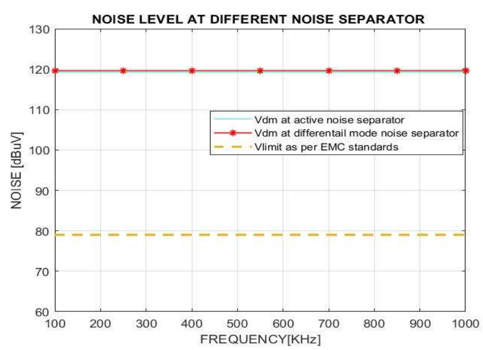

Figure 5: Noises at The Output of Noise Separators with Limit Line

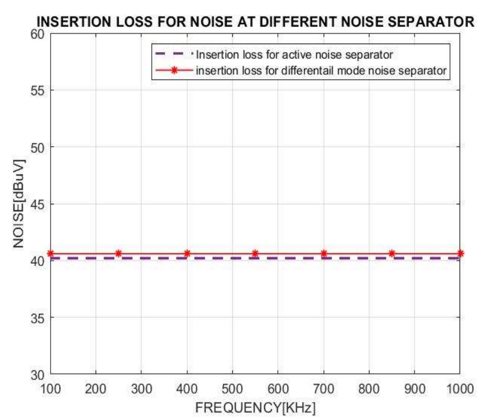

Figure 6: Insertion Loss Value for Different Noise Separator

3. DEVELOPED A SYSTEM MODEL FOR DIFFERENTAIL MODE EMI FILTER

The model consists of power converters called SEPIC is considered as the equipment, the two- stage Line Impedance Stabilization Network (LISN) circuit. DC power supply to run the equipment. The noise generated by this equipment is separated by using Noise separator gives common mode and differential mode noise [20]. The elimination of these noises is done by using EMI filter [21].

The EMI filters are used to protect the electronic devices from high power signals generated by the other electronic devices. The design of filter characteristics depends upon the noise generated by the devices, active and passive EMI filter are used for the reduction of noise in the electronic devices[22]. The design of filter for reduction of noise from noise separator is done with two types of filters The Power line filter and PI filter. The total measurement setup with power line filter is shown in fig 7.

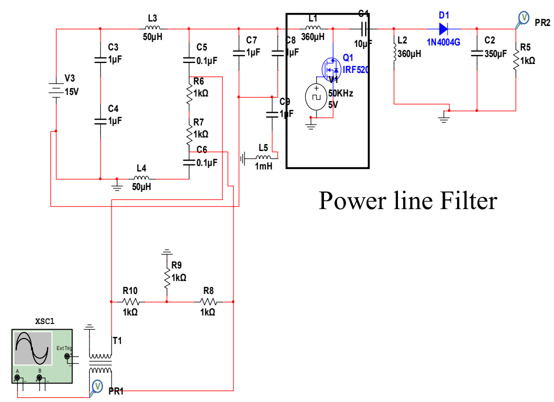

Figure 7: Measurement Setup with Power Line Filter For Reduction of Noise

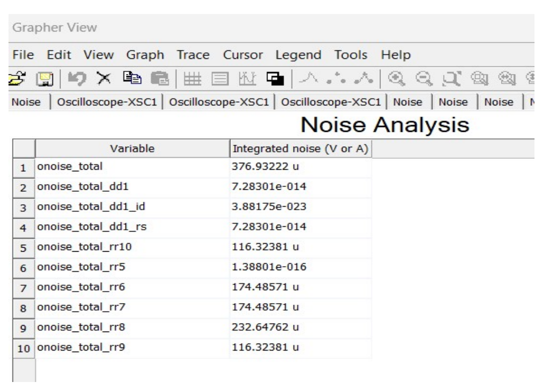

Figure 8: Noise Obtained at the Output of Noise Separator when Power Line Filter is Added

Journal of Theoretical and Applied Information Technology
15th May 2023. Vol.101. No 9

ISSN: 1992-8645 www.jatit.org E-ISSN: 1817-3195

The noise obtained from the noise analysis when the Power line filter is added to the system which is shown in fig.8. The noise obtained is converted into dBμV by using the equation 3 to check whether the filter meets the CISPR 22 standard requirements.

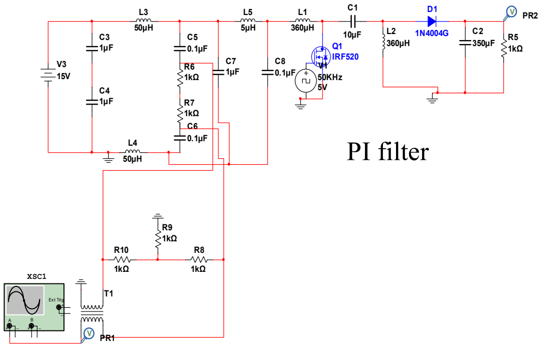

Figure 9: Measurement Setup With PI Filter For Reduction Of Noise

Table 3: The Noise Levels At The Output Of Filters

Filters used	Noise in [μV]	Noise in $dB_{\mu V} = 20log_{10}[\mu V]$
Power Line Filter	376.92	51.5
PI filter	407.07	52.2

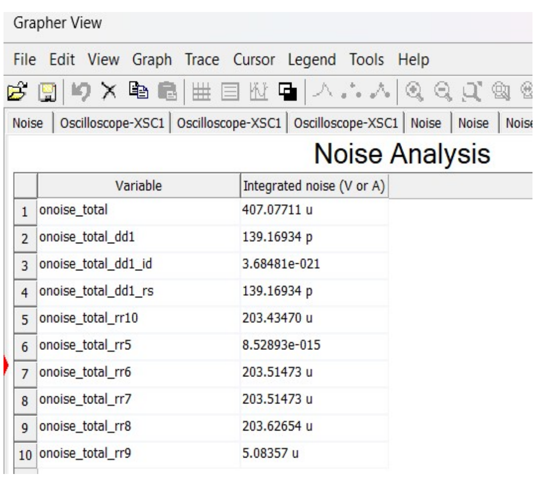

Figure 10: Noise Obtained at The Output of Noise Separator When PI Filter Is Added

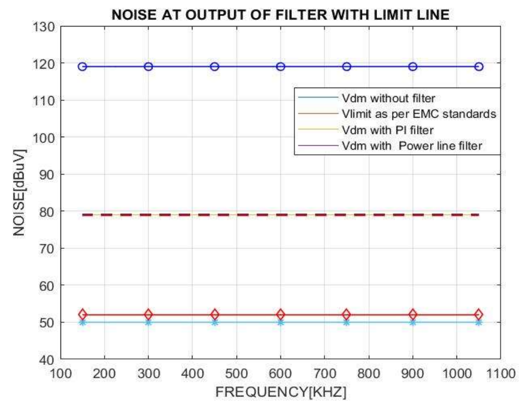

Figure 11: Noise Obtained with No Filter With Filters and Limit Line as Per EMC Standard

Figure 12: Insertion Loss Value For No Filter With Filters And Limit Line As Per EMC Standard

3.1 Line Impedance Stabilization Network[lisn]

The LISN is arranged in between the DC power supply and the equipment under test to maintain the constant output impedance of 50 ohms with no change in input voltage it acts as a filter

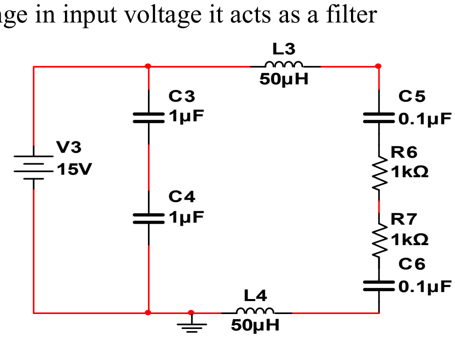

Figure 13: LISN Circuit

ISSN: 1992-8645 www.jatit.org E-ISSN: 1817-3195

3.2 Equipment

The equipment used in this paper for generation of noise is SEPIC Power converter which acts as a book converter or boost converter depend upon the duty cycle. SEPIC is DC-DC power converter is acts as a noise source due to switching elements in the circuit. The selection of components for the power converter is calculated by considering the input voltage and frequency of operation. The conducted signal has the frequency range of 150KHz to 3MHz. The below fig shows the power converter with LISN with DC power supply.

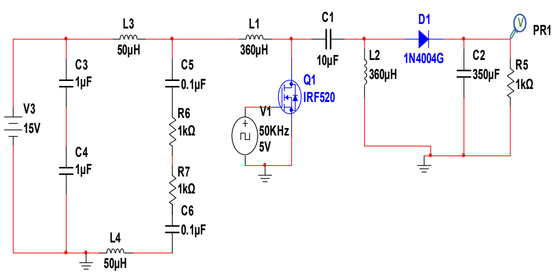

Figure 14: Power Converter With LISN

The Single Ended Primary Inductor [SEPIC] is a DC-DC power converter, the power conductor works as buck or boost converter depend upon the input voltage and frequency of operation [23]. In this experimental set up the SEPIC works as a Boost converter which produce step up in output voltage when input voltage is applied.

4. RESULTS

The differential mode noise is measured from the equipment using noise separator and the noise produces from the equipment is reduced by the EMI filter and increase the performance of the system. The signal radiates in the conducted mode has a frequency range of 150 KHz to 30MHz. The equipment used in this measurement setup is SEPIC power converter it acts as a noise source, the LISN is connected to the equipment to produce a constant output impedance of 50ohms. The noise measurement is done with two noise separators, which eliminates the common mode noise and produce a differential mode noise at the output of the noise separator. The comparison between the two nose separators are done, there is a very small change in the output. The measurement of noise at differential mode noise separator is 119.6 dBµV, The noise generated at the output of active noise separator is 119.2dBµV.

The insertion loss for the noise generated without filter is 40dBµV the insertion loss of an EMI filter designed to be more than the insertion loss without filter. The EMI filter used for reduction of noise as per CISPR standard is Power line filter and PI filter. The PI filter has a better performance in reduction of differential mode noise as per CISPR standard. The design process is done in MULTISIM software and results are plotted in simulation tool called MATLAB. The results obtained for the measurement setup is shown in below table

Table 4: Noise Levels In The Measurement Setup

Specifications	Noise in $[\mu V]$	Noise in $dB_{\mu V} = 20log_{10}[\mu V]$
Noise measured without filter	956 µV	119.6 dBµV
Noise at Power line filter	376.92 µV	51.5 dBµV
Noise at PI filter	407.07 µV	52.2 dBµV

5. CONCLUSION

The interference can occur inside the equipment or from outside the environment, the electromagnetic interference can be reduced by using different Electromagnetic Interference standards. For industrial applications CISPR 22 standard is considered for reduction of noise generated inside the equipment. The interference occurs inside the equipment is due to conducted mode, this mode has a frequency range of 150 KHz-30 MHz. The elimination of noise is done by designing an appropriate EMI filter with consideration of various parameters like frequency of operation, insertion loss.

The different type of EMI filter is designed in the past literature survey like hybrid differential mode EMI filter, choke filter, T filter, n-stage active EMI filter, these filters are used for reduction of noise for DC-DC power converter. In this paper low cost passive EMI filter with single stage is designed for reduction of noise generated by the power converter. The noise generated by the power converter is measured at the output of noise separator is 119 dBµV.

so, the filter is designed such that the noise levels has to be reduced as per the CISPR std. The filter design should consider the insertion loss and switching frequency. The insertion loss of the designed filter considers being more than the loss without filter. The noise at the output of power line filter is 51.5 dBµV and with PI filter is 52.2 dBµV. The designed filter meets the EMI standard called CISPR 22. Hence PI filter is good for reduction of noise as per EMI standards in conducted mode ranges from 150 KHz-1MHz.

REFERENCES

[1] C. R. Paul, "Introduction to Electromagnetic Compatibility", 2nd ed. Hoboken, New Jersey, USA: Wiley, 2006.

[2] Klaus Raggl,Thomas Nussbaumer, Johann W.Kolar, "Guideline for a Simplified Differential-Mode EMI Filter Design", *IEEE transactions on industrial electronics*, VOL. 57, NO. 3, MARCH 2010.

[3] P.Ram Mohan, M.Vijay Kumar, O.V. Raghava, "A novel topology of EMI filter to suppress common mode and differential mode noises of electromagnetic interference in switching mode power supplies", *ARPN Journal of Engineering and Applied Sciences*, VOL. 2, NO. 4, AUGUST 2007 ISSN 1819-6608

[4] V. S. C. Pathala and P. V. Y. Jayasree, "Design of a Shielded Room against EMP Signal as per MIL-STD 461", *Eng. Technol. Appl. Sci. Res.*, vol. 13, no. 1, Feb. 2023, pp. 9837–9842.

[5] G. Ala, G. C. Giaconia, G. Giglia, M. C. Di Piazza, and G. Vitale, "Design and performance evaluation of a high power-density EMI filter for PWM inverter-fed induction-motor drives", *IEEE Trans. Ind. Appl*., vol. 52, no. 3, May–Jun. 2016, pp. 2397–2404.

[6] M. Hartmann, H. Ertl, and J. W. Kolar, "EMI filter design for a 1 MHz, 10 kW three-phase/level PWM rectifier", *IEEE Trans. Power Electron.*, vol. 26, no. 4, Apr. 2011, pp. 1192–1204.

[7] K. Mainali and R. Oruganti, "Conducted EMI mitigation techniques for switch-mode power converters: A Survey", *IEEE Trans. Power Electron.*, vol. 25, no. 9, Sep. 2010, pp. 2344–2356

[8] R. Goswami and S. Wang, "Modeling and Stability Analysis of Active Differential-Mode EMI Filters for AC/DC Power Converters", in *IEEE Transactions on Power Electronics*, vol. 33, no. 12, pp. Dec. 2018, 10277-10291. doi: 10.1109/TPEL.2018.2806361.

[9] A. PÉrez, A. -M. SÁnchez, J. -R. ReguÉ, M. RibÓ, P. RodrÍguez-Cepeda and F. -J. Pajares, "Characterization of Power-Line Filters and Electronic Equipment for Prediction of Conducted Emissions", in *IEEE Transactions on Electromagnetic Compatibility*, vol. 50, no. 3, Aug.2008, pp.577-585. doi: 10.1109/TEMC.2008.926891.

[10] K. Raggl, T. Nussbaumer and J. W. Kolar, "Guideline for a Simplified Differential-Mode EMI Filter Design", in *IEEE Transactions on Industrial Electronics*, vol. 57, no. 3, March 2010,pp.1031-1040.doi: 10.1109/TIE.2009.2028293.

[11] Nourani Esfetanaj, Naser, Huai Wang, Frede Blaabjerg, and Pooya Davari. 2021 "Differential Mode Noise Estimation and Filter Design for Interleaved Boost Power Factor Correction Converters", *Applied Sciences* 11, no. 6: 2716. https://doi.org/10.3390/app11062716

[12] X. Chang, W. Chen, Y. Yang, K. Wang and X. Yang, "Research and realization of a novel active common-mode EMI filter", 2015 *IEEE Applied Power Electronics Conference and Exposition (APEC)*, Charlotte, NC, USA, 2015, pp.1941-1945. doi: 10.1109/APEC.2015.7104612.

[13] Y. Zhang, H. Li and Y. Shi, "Electromagnetic Interference Filter Design for a 100 kW Silicon Carbide Photovoltaic Inverter Without Switching Harmonics Filter", in *IEEE Transactions on Industrial Electronics*, vol. 69, no. 7, July 2022, pp. 6925-6934. doi: 10.1109/TIE.2021.3095806.

[14] R. Goswami and S. Wang, "Modeling and Stability Analysis of Active Differential-Mode EMI Filters for AC/DC Power Converters", in *IEEE Transactions on Power Electronics*, vol. 33, no. 12, Dec. 2018, pp. 10277-10291. doi: 10.1109/TPEL.2018.2806361.

[15] K. Raggl, T. Nussbaumer and J. W. Kolar, "Guideline for a Simplified Differential-Mode EMI Filter Design", *in IEEE Transactions on Industrial Electronics*, vol. 57, no. 3, March 2010,pp.1031-1040, doi: 10.1109/TIE.2009.2028293.

[16] K. Mainali and R. Oruganti, "Conducted EMI mitigation techniques for switch-mode power converters: A Survey", *IEEE Trans. Power Electron.*, vol. 25, no. 9, Sep. 2010, pp. 2344–2356.

ISSN: 1992-8645 www.jatit.org E-ISSN: 1817-3195

[17] S. Wang, Y. Y. Maillet, F. Wang, D. Boroyevich, and R. Burgos, “Investigation of hybrid EMI filters for common-mode EMI suppression in a motor drive system”, *IEEE Trans. Power Electron.*, vol. 25, no. 4, , Apr. 2010, pp. 1034–1045.

[18] CISPR 22, “Information Technology Equipment—Radio Disturbance Characteristics—Limits and Methods of Measurement” , *Int. Electrotech.Comm*., Nov. 1997.

[19] M. C. Caponet, F. Profumo, L. Ferraris, A. Bertoz and D. Marzella, “Common and differential mode noise separation: comparison of two different approaches”, *2001 IEEE 32nd Annual Power Electronics Specialists Conference* (IEEE Cat. No.01CH37230), Vancouver, BC, Canada, 2001, vol. 3, pp. 1383-1388. doi: 10.1109/PESC.2001.954313.

[20] K. Raggl, T. Nussbaumer and J. W. Kolar, "Guideline for a Simplified Differential-Mode EMI Filter Design," in IEEE Transactions on Industrial Electronics, vol. 57, no. 3, pp. 1031-1040, March 2010, doi: 10.1109/TIE.2009.2028293.

[21] MOHIT KUMAR ,VIVEK AGARWAL, “Power Line Filter Design for Conducted Electromagnetic Interference Using Time-Domain Measurements*”, IEEE Transactions on electromagnetic compatibility*, VOL. 48, NO. 1, FEBRUARY 2006.

[22] J. Biela, A. Wirthmueller, R. Waespe, M. L. Heldwein, K. Raggl and J. W. Kolar, "Passive and Active Hybrid Integrated EMI Filters," in IEEE Transactions on Power Electronics, vol. 24, no. 5, pp. 1340-1349, May 2009, doi: 10.1109/TPEL.2009.2012404.

[23] S. Biricik, T. Ngo, H. Komurcugil and M. Basu, "Nonlinear control methods for single-ended primary-inductor power converters," IECON 2017 - 43rd Annual Conference of the IEEE Industrial Electronics Society, Beijing, China, 2017,pp.1337-1340,

doi: 10.1109/IECON.2017.8216227.