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A New Passive Filter Design for Harmonic Mitigation

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***Abstract*: -- Passive filters are generally preferred in power converters to nullify the high-frequency harmonics caused by pulse width modulation (PWM). Employment of passive filters is an effectual solution that can be used to attain harmonic mitigation to a greater extent mainly because filters are put forward to increase the efficiency. Isolated DC-DC converters were usually used topologies. In power electronics application half-bridge converter is one of the suitable converters. Stress on the switches can be minimized by using the half-bridge converter. Hence, half bridge converter is modified based on the application and LLCCLL filter is connected at the input side to reduce the input side harmonics. With these notes taken into account, the objective of this paper is to design a new topology of passive LLCCLL filter for harmonic mitigation. Thus, it also improves the power factor of the load. Hence, simulation is carried out in P-SIM software and hardware implementation will carry out in the medical x-ray equipment to measure the reduction of the harmonic level.**

Index Terms: **Passive filter, pulse width modulation, half bridge converter, LLCCLL filter.**

I. INTRODUCTION

Harmonic distortion of current and voltage waveforms have become a concern in power system in topical years due to the extensive use of loads that generate currents with high frequencies. Occurrence of harmonics in a power system can go up to a assortment of problems together with equipment overheating, decreased power factor, deteriorating performance of electrical apparatus, the inaccurate function of protective relays, and other type of rigorous damage [1]. Yet not as good as, harmonic currents generated in one part can go through the network and spread into former parts of the system, ensuing in voltage and current distortions for the complete system. This trend has become a most vital concern to the power quality because of increased use of electronic devices in power systems. The harmonic distortion happens when non-linear loads, such as rectifier, inverter, etc., are fed from power systems and alteration in sinusoidal waveform at a basic frequency to changed non-sinusoidal waves. On the other hand the most suitable technical tools that can be used to reduce the choral voltages are passive and active filters, and these are used to factor correction and harmonic mitigation. In contrast harmonic distortion levels can be minimized by connecting passive filters or by improving the design of contaminated loads. Therefore, passive filters have been located as a key to harmonic suppression [1].

It can be argued that active filters have better performance for harmonic reduction and for PF correction when related to other types of harmonic filters. Also, they do not establish resonance that can cause harmonic problem from one frequency to other one. However, active filters are not widely used in the industry generally because those filters are costlier. Moreover, they necessitate sophisticated control algorithm and convoluted alternatives to run the circuits [1]. They are selected as most suitable technical tools to apply and more quantity of variety of topologies is projected. Therefore, passive filters are commonly used in power systems and well thought-out enhanced selection of these filters because of their uncomplicated construction, reliability is good and it does not need much running cost.

II. LITERATURE SURVEY

In literature, several studies have been presented regarding on harmonics mitigation by using different types of filter. Almost filter designs are L, LC and LCL types and found that only these topologies were used to reduce the harmonic level. All are conventional type topologies. Passive filter is one of them and has been investigated for harmonic suppression.

III. PROPOSED SYSTEM

A. ISOLATED HALF BRIDGE DC-DC CONVERTER:

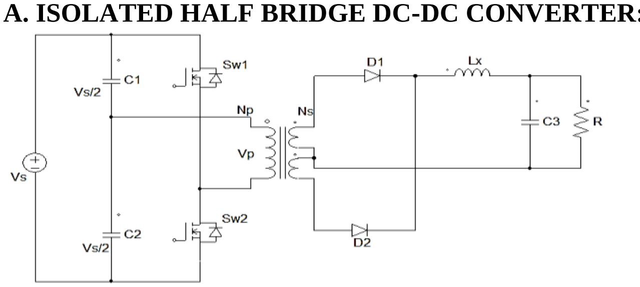

Fig-3.1 Isolated half bridge dc-dc converter.

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Fig-3.1 shows circuit diagram of isolated half bridge dc-dc converter [4]. Due to simplicity of the half bridge DC-DC converter it is used in electronics filed. To reduce the stress on the switches this converter is best one to use. Another important feature is that it diminishes the off state voltage pressure. Hence component price and stress can be reduced. To drive the transformer two MOSFET switches are used. Across the DC voltage two same ratings capacitors are used in the converter. Duty cycle is same for both the switches and conduct for the same value [2]. Usually to remove the dc bias in the transformer full bridge converter needs extra capacitors. But in the proposed converter there is no need of any extra capacitors. Both the switches itself adjust the change in variations by varying their voltage level [2].

B. PASSIVE FILTER TOPOLOGY:

Here, proposed new filter design is to reduce the size and cost of the filter along with control of harmonics and also to improve the efficiency and power factor. Filter is easy in construction, reasonable price and to work in poorer circumstance devoid of damaging the equipment. A simple method to weaken the harmonic is, use of a LLCCLL filter.

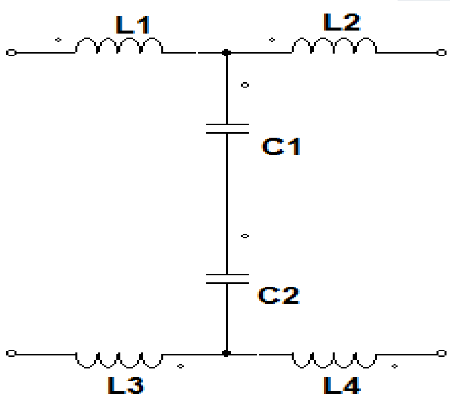

Fig-3.2 Passive LLCCLL filters topology.

Fig-3.2 shows the LLCCLL passive filter topology. LLCCLL filter contains four inductors connected in parallel with two capacitors. This is a new type of passive filter topology. For suppressing the harmonic distortion passive filtering is easiest way out. Passive components like inductors and capacitors are used. P-SIM software is used to simulate the half bridge isolated dc-dc converter with passive filter. Harmonics creates the dangerous issues to the electrical equipments. Therefore, it is important to suppress these harmonics for the secure operation of electrical equipments.Hence, a new topology of passive LLCCLL filter is proposed. This design is to minimize the harmonic content and cost effective along with reduction of size of the filter and also to improve the efficiency and power factor.

C. BLOCK DIAGRAM:

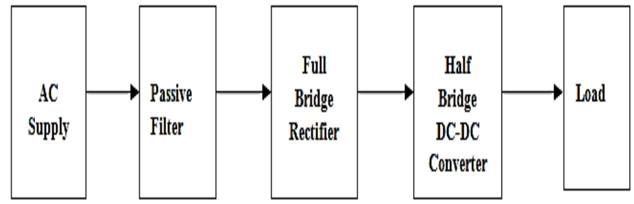

Fig-3.3 Block diagram of LLCCLL filter with half bridge dc-dc converter.

Fig-3.3 shows the block diagram of hardware implementation. It consists of bridge rectifier and isolated half bridge dc-dc converter with passive filter and load. X-ray tube is considered as a load and it is purely resistive.

IV. PASSIVE FILTER DESIGN CONSIDERATION

The common design principle of the passive filter is to accomplish non-linear and multi-purpose optimization, but attaining to a greater level is very complicated. There are definite principles that should be taken in to account to get most favourable design, as [1] Designed component of filters values should be work in worst operating condition and to stay away from the damages and also to meet up the technical necessities [1]. The inductor and capacitor costs are made on to the same and relative to their ratings [1].

Selection of proper size of inductor and capacitor is a major role in passive filter design. To avoid large volume inductance L should be kept lesser value. Minimum value of inductance L keeps the output impedance less. Most important thing is to keep the capacitor value in such a range that it must give good power factor. Hence correct choice of the capacitor is very important consideration in power factor point of view. By giving less resistance passage way to the ground the capacitor will attenuates the harmonics. To avoid the larger currents it is necessary to kept low value of capacitance because these larger currents can cause dangerous hazards to the switching devices [3].

REQUIREMENT OF THE LLCCLL FILTER:

Main requirement of the LLCCLL filter is to avoid switching harmonics. These switching harmonics will propagate from load to source and it may damage the load by introducing the harmonics. To avoid this problem need to buildup high dc voltage. Hence LLCCLL filter is modeled and connected at the input side to restrict the entry of harmonics.

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V. LLCCLL FILTER TRANSFER FUNCTION

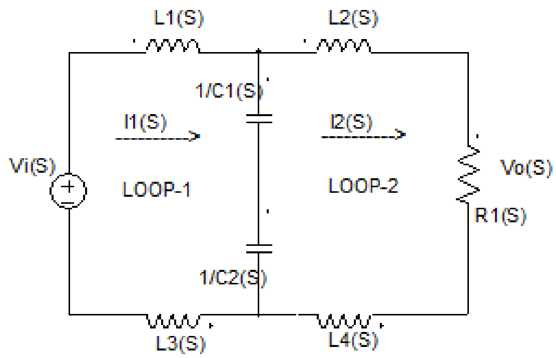

Fig-5.1 shows the LLCCLL filter system model.

Apply KVL to the loop-1

$$V_i(S) = \left(L_1S + \frac{1}{C_1S} + \frac{1}{C_2S} + L_2S \right) I(S)$$

$$V_i(S) = \left[\frac{C_1C_2L_1S^3 + C_1C_2L_2S^3 + 1}{C_1C_2S^2} \right] I(S) \text{..........(1)}$$

Apply KVL to the loop-2

$$V_O(S) = \left(R_1S + L_3S + L_4S + \frac{1}{C_1S} + \frac{1}{C_2S} \right) I(S)$$

$$V_O(S) = \left[\frac{C_1C_2R_1S^3 + C_1C_2L_3S^3 + C_1C_2L_4S^3 + 1}{C_1C_2S^2} \right] I(S) \text{..........(2)}$$

$$I(S) = \frac{V_O(S) \times C_1C_2S^2}{1 + C_1C_2R_1S^3 + C_1C_2L_3S^3 + C_1C_2L_4S^3} \text{..........(3)}$$

Substitute equation (3) in equation (1)

$$Vi(S) = \left[\frac{1 + C_1C_2L_1S^3 + C_1C_2L_2S^3}{C_1C_2S^2} \right] \left[\frac{V_O(S) \times C_1C_2S^2}{1 + C_1C_2R_1S^3 + C_1C_2L_3S^3 + C_1C_2L_4S^3} \right]$$

$$\frac{V_O(S)}{V_i(S)} = \frac{1 + C_1C_2R_1S^3 + C_1C_2L_3S^3 + C_1C_2L_4S^3}{1 + C_1C_2L_1S^3 + C_1C_2L_2S^3}$$

$$\frac{V_O(S)}{V_i(S)} = \frac{1 + C_1C_2S^3\left[R_1 + L_3 + L_4\right]}{1 + C_1C_2S^3\left[L_1 + L_2\right]} \text{..........(4)}$$

Equation (4) shows the LLCCLL filter transfer function.

VI. CALCULATION OF REFLECTED RESISTANCE:

Transformer changes both voltage and current on the primary side (Rpri) of the transformer to different values on the secondary side of the transformer. Load resistance (RL) appears to the primary side of the transformer as a resistance Rpri. RL is reflected into primary side as determined by transformer turns ratio (K); known as "Reflected Resistance". Below fig-6.1 shows the connection of reflected resistance at primary side of the transformer.

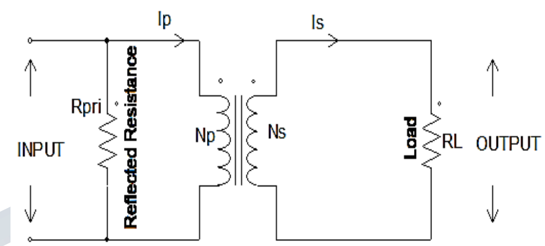

Fig-6.1 Connection of reflected resistance at primary side of the transformer.

Here, number of turns on primary & number of turns on secondary side of transformer are considered as 1 and 352 respectively. Maximum power output of this project is 50Kw. X-ray tube is considered as a load. Voltage range of x-ray tube lies in between 40kV to 150kV and current range of x-ray tube lies in between 630mA to 330mA. For these values of voltage and current, load resistance values are calculated using ohms law.

From ohms law,

$$\text{Resistance} = \frac{\text{Voltage}}{\text{Current}}$$

$$R = \frac{V}{I}$$

$$R = \frac{40 \times 10^3}{630 \times 10^{-3}}$$

$$R = 63.49K\Omega$$

Similarly, for voltage values of 80kV, 150kV and current values of 630mA, 330mA load resistances are calculated respectively. 126.98kΩ and 454.54kΩ are the calculated load resistances.

Next, Reflected resistance calculation is done using the already calculated load resistance values and already considered turns of primary and secondary of transformer.

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$$\text{Transformer turns ratio (K)} = \frac{\text{Number of turns on secondary side of the transformer } (N_{sec})}{\text{Number of turns on primary side of the transformer } (N_{pri})}$$

$$K = \frac{N_{sec}}{N_{pri}}$$

$$K = \frac{352}{1}$$

$$K = 352$$

$$R_{pri} = \frac{R_L}{K^2}$$

Where,

R_{pri} is the reflected resistance of primary side of the transformer

R_L is the load resistance of secondary side of the transformer

$$R_{pri} = \frac{63.49 \times 10^3}{(352)^2}$$

$$R_{pri} = 1.02\Omega$$

Thus for different values of load resistances, reflected resistances are calculated. Also, simulation is done with different switching frequencies.

X-ray tube voltage in (kV)	X-ray tube current in (mA)	Load resistance in (kΩ)	Reflected resistance (Ω)	Switching frequency (kHz)
40	630	63.49	0.512	48.5
80	630	126.98	1.02	47.6
150	330	454.54	3.66	47

Table-3 shows the calculated values of reflected resistance for different switching frequencies.

VII.PARAMETERS FOR DESIGN

SL.NO	COMPONENTS WITH VALUES	QUANTITY
1	Capacitors 19.8uF - (C1 & C2) 220uF - (C3 & C4) 1nF - (C5 & C6) 3uF - (C7) 10nF - (C8, C9 & C10)	 2 2 2 1 3
2	Inductors 3uH - (L1 to L7) 3.38uH - (L8)	 7 1

Table-1 components list used to design.

Table-1 shows the components list to design. Components are selected based on the requirements. Transformer, Diodes and MOSFETs are taken based on the requirements. The transformer turns ratio of primary & secondary windings are, Np=1 and Ns=352 respectively.

VIII. SIMULATION & RESULTS

A. SIMULATION PARAMETERS:

Parameters	Values
Supply voltage	380V
Supply Frequency	50Hz
Duty cycle	0.9
Switching frequency	48kHz

Table-2 List of simulation parameters.

Table-2 shows the list of simulation parameters which are considered for simulation process.

B. CIRCUIT DAIGRAM OF HALF BRIDGE DC-DC CONVERTER WITH LLCCLL FILTER:

In order to verify the proposed LLCCLL passive filter a small experimental setup is constructed in P-SIM software as shown in fig-8.1.

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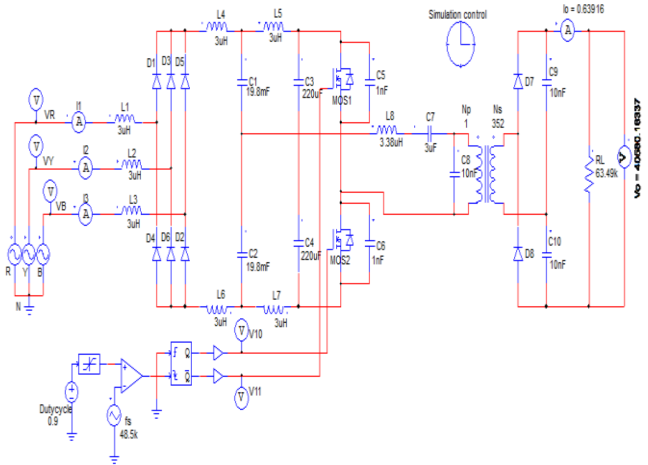

Fig-8.1 circuit diagram of LLCCLL filter design with bridge rectifier, half bridge dc-dc c0nverter and load.

Fig-8.2 shows the design of passive filter. It consists of full bridge diode rectifier and half bridge isolated dc-dc converter was used. Purely resistive load is considered.

IX. INPUT WAVEFORMS

WITHOUT SOURCE INDUCTANCES:

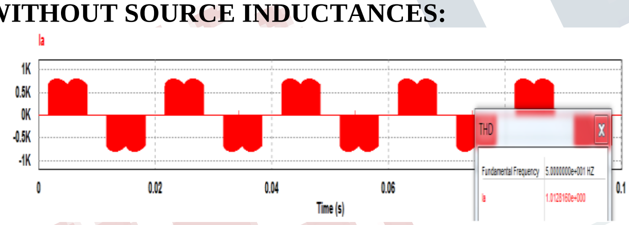

Fig-9.1 Input current waveform.

Fig-9.1 shows the input line current waveform without source inductances. THD is about 101% before adding inductances to line.

WITH SOURCE INDUCTANCES:

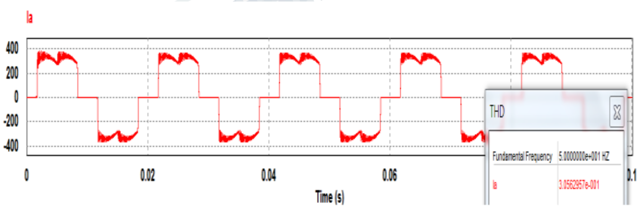

Fig-9.2 Input current waveform.

Fig-9.2 shows that the input line current waveform with addition of line inductances. After adding harmonics line inductances the harmonics get reduced. Measured THD content is 30%.

X. OUTPUT WAVEFORMS

OUTPUT VOLTAGE & OUTPUT CURRENT WAVEFORM:

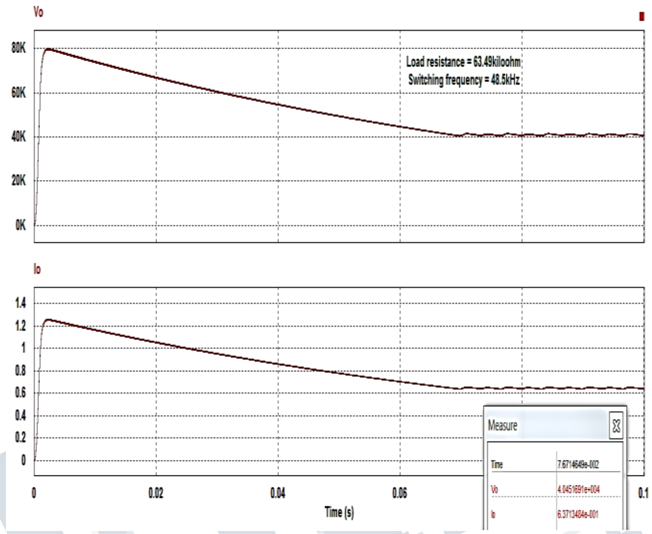

Fig-10.1(a) output voltage waveform for load resistance value 63.49kΩ.

Fig-10.1(a) shows the output voltage waveform for load resistance (RL) of 63.49kΩ and switching frequency (fs) of 48.5 kHz. For these values of RL and fs obtained output voltage and current is 40.40kV and 0.636Amp respectively.

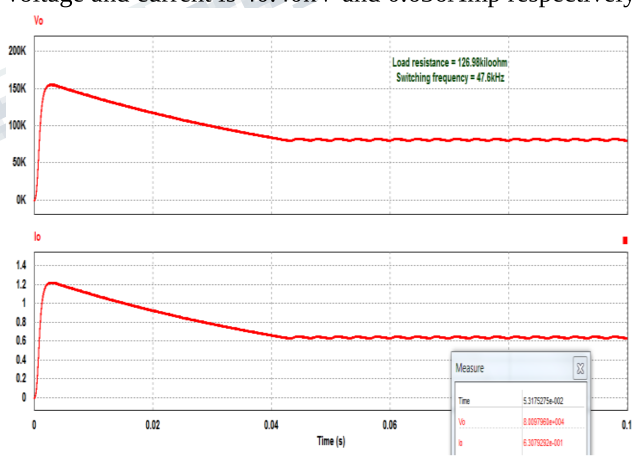

Fig-10.1(b) output voltage waveform for load resistance value 126.98kΩ.

Fig-10.1(b) shows the output voltage waveform for load resistance (RL) of 126.98kΩ and switching frequency (fs) of 47.6 kHz. For these values of RL and fs obtained output voltage and current is 80.02kV and 0.630Amp respectively.

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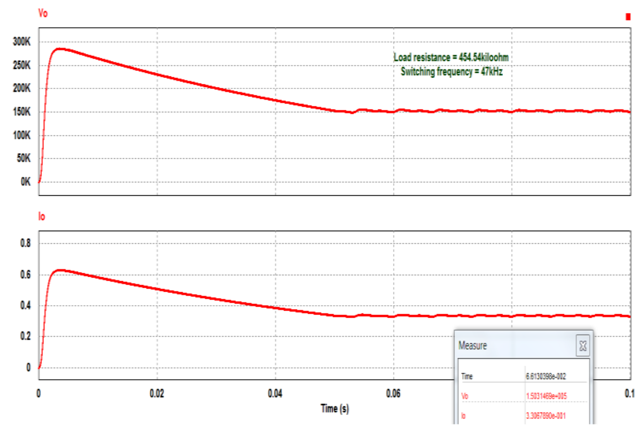

Fig-10.1(c) Output waveform for load resistance value 454.54kΩ.

Fig-10.1(c) shows the output voltage waveform for load resistance (RL) of 454.54kΩ and switching frequency (fs) of 47 kHz. For these values of RL and fs obtained output voltage and current is 150.2kV and 0.330Amp respectively.

FREQUENCY RESPONSE OF LLCCLL FILTER:

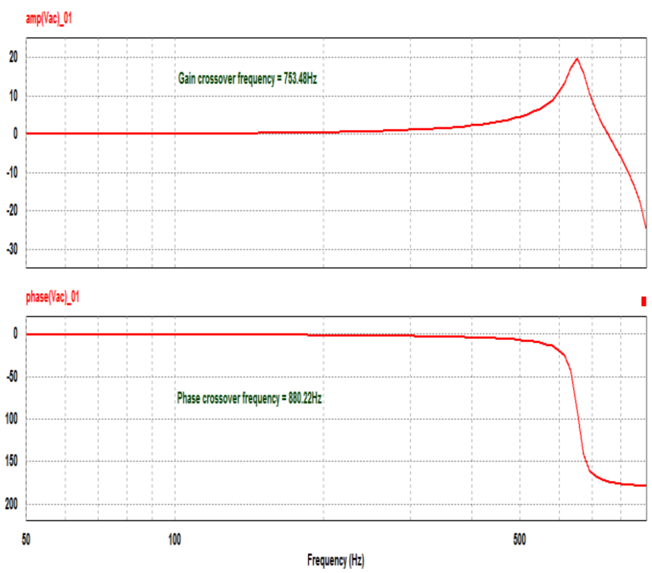

Fig-10.2 Frequency responses of LLCCLL filter topology.

Fig-10.2 shows the frequency response of the LLCCLL filter topology. Above figure includes both magnitude and phase plots. From that plot gain margin and phase margins are measured. Gain crossover frequency is 753.48Hz and Phase crossover frequency is 880.22Hz.

Gain Margin (GM)= [0-(G)]

GM=[0-(-19.37)]

GM=19.37db

Phase Margin (PM)= $(180^{O} + \theta)$

PM= $[180^{O} + (-173.20^{O})]$

PM= 6.8^{O}

Gain margin (GM) is 19.37db and Phase margin (PM) is 6.8deg. Phase margin and gain margin both are positive. Hence the system is stable. Also filtering action takes place at 50Hz and it ends before 880.22Hz frequency by completing harmonic reduction process. All harmonics are getting eliminated before frequency 880.22Hz. Hence the designed filter is working properly.

XI. FUTURE WORK

To find at what percent harmonics get reduced will be checked by using THD calculation. Hardware implementation will carry out in future in the medical x-ray equipment and verify with simulation results.

XII. CONCLUSION

In this paper proposed technique of half bridge isolated dc-dc converter with a new topology of passive filter is designed and simulated. It is observed that new LLCCLL passive filter is more effective and efficient design to improve the harmonic distortion level and power factor of the load.

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