THE ANALYSIS OF IMPEDANCE MISMATCH ON THE CONDUCTED EMI EMISSION

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Abstract: This paper proposes the process to predict and analyze the conducted electromagnetic interference (EMI) emission using the impedance mismatch approach. Five steps of this process are introduced and analyzed. The impedance mismatch criterion is proposed based on current and voltage waveforms in time domain. The impedance mismatch fixtures and EMI measured results show how the relationship of impedance ratio and conducted EMI emission are occurred. This work is done using a class E zero-voltage switching (ZVS) resonant inverter at various loaded conditions: unity, lagging and leading power factors. The experimental results show some good agreements with the simulated results, which are accomplished by MATLAB program.

Keywords: Conducted EMI emission, prediction, impedance mismatch, Class E ZVS resonant inverter

1. Introduction

In recent years, the EMI emission has been interested and proved by many published papers. Some papers showed the processes to reduce the EMI, some papers approved the implements by the simulations, and some papers explained the EMI by their techniques. In this paper, the EMI prediction is presented. This paper proposes the conducted EMI emission analysis using the mismatch of impedance in each part of the circuit. The first step of this method is to consider each part of circuit separately; such as to consider the rectifier circuit from the inverter circuit and load separately, as shown in Figure 1. The impedance and power of each part can be measured and calculated by oscilloscope and some basic software. These results can be analyzed and supported by the conducted EMI emission measurement.

The experiment shows the relationship of the conducted EMI emission trend and the impedance mismatch, when loaded impedance is various. The proposed circuit uses an induction coil as the load; therefore, it is the resistive-inductive load. The selected capacitor is used to change the loaded power factor from lagging to unity and also leading power factors. These three cases of load are used to compare the impedance mismatch and power mismatch of this circuit with its conducted EMI emissions; where the input power of each condition is constant at 1000 W. This paper shows a basic concept and an example to prove and explain this method. For any applied circuits, this method can also be used for the emission predicting, but users have to simplify their circuits first.

2. Class E ZVS Resonant Inverter

The "Class E" power amplifiers as shown in Figure 2 were developed by Sokal [1] in the mid 1970s for use in lightweight, low power, high efficiency power converters and RF amplifiers. The Class E ZVS resonant inverters are most efficient inverters known. In particular, the switch turns on at zero voltage if the component values of the resonant circuit are properly chosen. So the switching losses are virtually zero, yielding high efficiency (approximately 96% [1-2]). When the inverter operated at high frequency in order to get high efficiency controlled. The output current and voltage waveforms of this circuit will be sinusoidal shape, if the loaded quality factor is high enough.

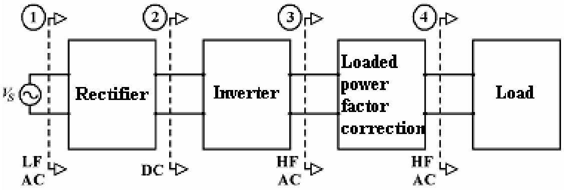

Figure 1. Four Impedance ports: Separating concept

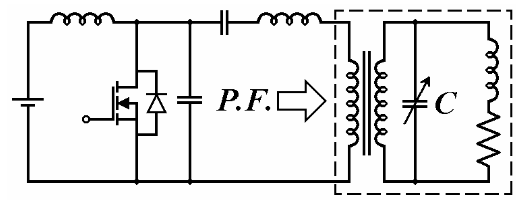

Figure 2. Improved power factor by connect the capacitor at the secondary side of transformer

The tested circuit is a class E ZVS resonant inverter, using the induction coil load with the selected capacitor as shown in Fig. 2. The use of this circuit is not only to reduce a number of switching devices and the amount of switching loss, but also generate predictable frequency. This circuit can generate both sinusoidal output current and voltage waveforms, when the loaded quality factor is high enough.

In this paper, the main contents are composed of the proposed circuits as shown in Figure 2 and their impedance approach, the comparison between the simulated results and measured results of inverter waveforms, the EMI analysis and prediction and the conclusion. The impedance is measured as shown in Figure 3.

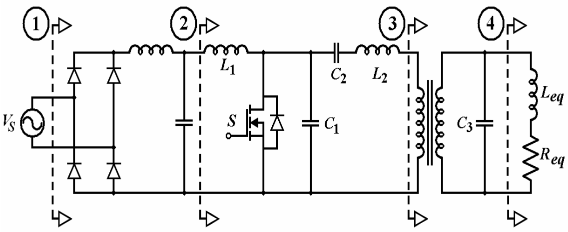

Figure 3 Proposed circuit

3. Step-by-Step Method

The proposed process, as shown in Table 1, can be described, the first step, starting by setting three different loaded power factors: unity, lagging and leading power factor. This condition must keep the same input power. This is the important criterion to compare the EMI emission. Then, the second step, the current and voltage waveforms at 4 key points are measured as shown in Figure 3.

Table 1. Research step by step method

Step	Descriptions
1	To operates the inverter at three different loaded power factors
2	To measure *i* and *v* waveforms at four key points
3	To calculate the impedance and power flow
4	To calculate the impedance mismatch using the impedance mismatch ratio
5	To predict and analyze the conducted EMI emission based on the impedance mismatch ratio

These results lead to calculate the impedance at four points: point 1 is at the AC terminal, point 2 is at the input of the class E inverter, point 3 is at the front end of transformer primary side, and point 4 is at the loaded side. The third step, the impedance of each point is calculated using MATLAB tool, where the data from oscilloscope are loaded to the computer in the MATLAB program. The simulated and measured results of current and voltage waveforms (i_d : 5A/div, v_{ds} : 500V/div, t : 2μs/div) are shown in Figures 4-7. The fourth step, the mismatch impedance is based on the impedance ratio at any point as shown in equation (1). This criterion is also done for the mismatch of the power flow as shown in equation (2). The example results of each circuit impedance and impedance ratio are done as shown in tables 2-3. The power flow details and power ratio are shown in table 4-5. Figures 8 and 9 are the histograms of impedance ratio from table 3 and power ration from table 5, respectively. They can show the difference of all cases easily.

Finally, the fifth step, the measurement setup and results of conducted EMI emission, as shown in Figures 11-17, are done at three different loaded power factors.

$$\text{Ratio of } Z \text{ at point} x = \left| \frac{Z \text{ at point } x \ - \ Z \text{ at point 1}}{Z \text{ at point 1}} \right| \quad (1)$$

$$\text{Ratio of } P \text{ at point} x = \left| \frac{P \text{ at point } x \ - \ P \text{ at point 1}}{P \text{ at point 1}} \right| \quad (2)$$

Some analyses reveal that at the unity load power factor, the lowest mismatch impedance, generate the lowest conducted EMI emission comparing to those of leading and lagging power factors as shown in Figures11-13

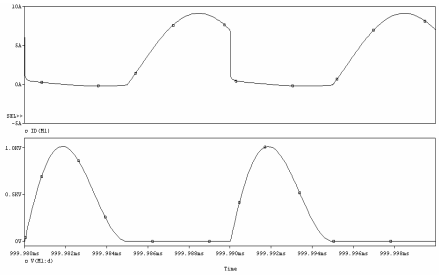

Figure 4 Simulated current and voltage waveforms at the power MOSFET, when the power factor is unity

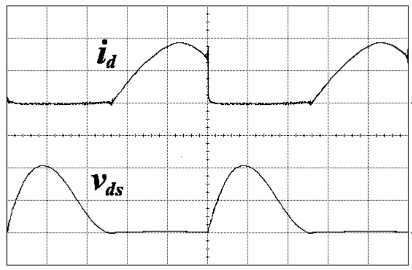

Figure 5 Experimental current and voltage waveforms at the power MOSFET, when the power factor is unity

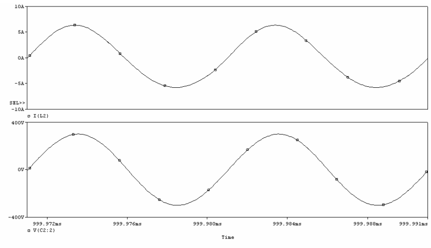

Figure 6 Simulated current and voltage waveforms at the transformer primary side, when the power factor is unity

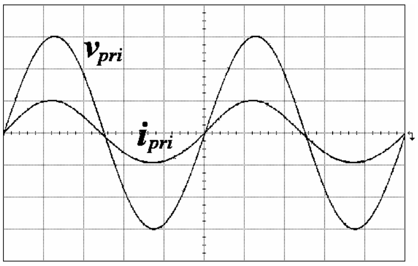

Figure7 Experimental current and voltage waveforms at the transformer primary side, when the power factor is unity

Table 2. Measured impedance at four points on Figure3

	Impedance (Ω)			
	Point 1	Point 2	Point 3	Point 4
Unity	39.09	87.39	54.61	4.52
Lagging	37.95	88.34	25.29	4.48
Leading	39.46	88.91	25.41	4.55

Note: Impedances are based on RMS values

Table 3. Impedance ratio at four points on Figure 3

	Impedance ratio (%)			
	Point 1	Point 2	Point 3	Point 4
Unity	-	123.56	39.70	88.44
Lagging	-	132.78	33.36	88.19
Leading	-	125.32	35.61	88.47

Table 4. Measured power at four points on Figure 3

	Power (W)			
	Point 1	Point 2	Point 3	Point 4
Unity	1000.00	919.75	830.71	812.09
Lagging	1000.00	916.92	790.04	773.69
Leading	1000.00	919.39	817.80	798.25

Note: Powers are based on RMS values

Table 5. Impedance ratio at four points on Figure 3

	Power ratio (%)			
	Point 1	Point 2	Point 3	Point 4
Unity	-	8.03	16.93	18.79
Lagging	-	8.31	21.00	22.63
Leading	-	8.061	18.22	20.175

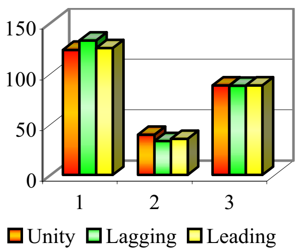

Figure 8 Comparison of impedance ratio from table 3

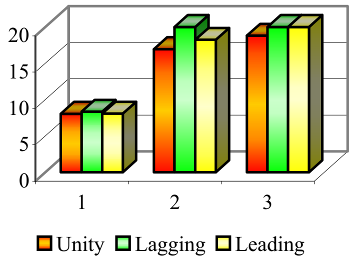

Figure 9 Comparison of power ratio from table 3

4. Conducted EMI Emission Measurement

The aim of this paper is to predict the conducted EMI emission in a circuit using the impedance mismatch approach. The simulated and experimental results have been tested using a class E ZVS resonant inverter at 1,000 W input powers, and the switching frequency of 100 kHz. The operating condition for the load can be done at unity, lagging and leading loaded power factor using the capacitor variation. The mismatch impedance at four different points shows both of power flow and conducted EMI emission to the utility grid. The line impedance stabilization network (LISN) is connected to provide acceptable measurement and impedance at the range of 9 kHz to 30 MHz. The limitation of the conducted EMI emission based on CISPR 11 Class B is used and setup as shown in Figure 10

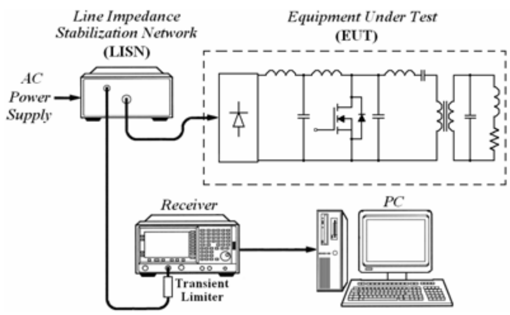

Figure 10 Measurement circuit

LISN: EMCO 3810/2 50 Ω, 50/250 μH, 9 kHz-30 MHz

Receiver: Agilent EMC analyzer E74011A, 9 kHz-1.5 GHz

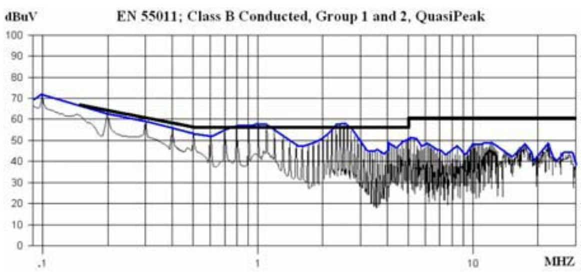

Figure 11 Conducted EMI emissions from the case of unity power factor, measured from 90 kHz to 30 Hz, the reference is set to 100 dBμV

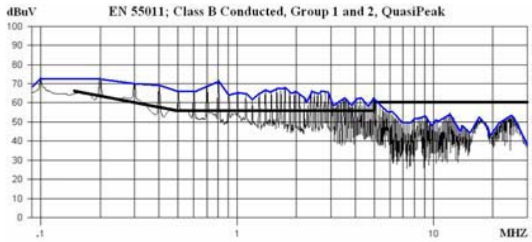

Figure 12 Conducted EMI emission from the case of lagging power factor, measured from 90 kHz to 30MHz, the reference is set to 100 dBμV

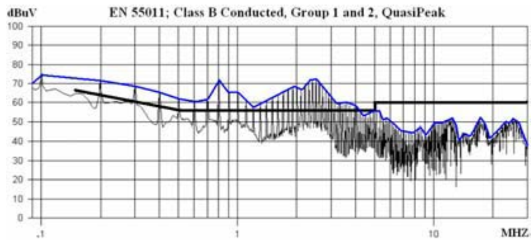

Figure 13 Conducted EMI emission from the case of leading power factor, measured from 90 kHz to 30 MHz, the reference is set to 100 dBμV

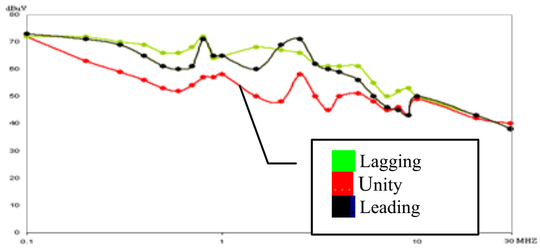

Figure 14 Comparison of envelope of 3 types P.F.

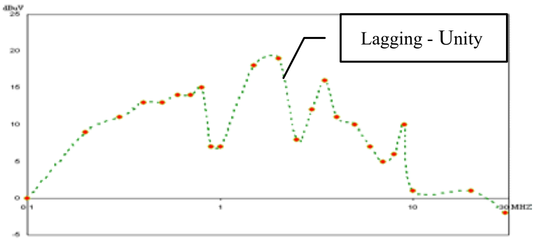

Figure 15 Comparison of lagging and unity P.F.

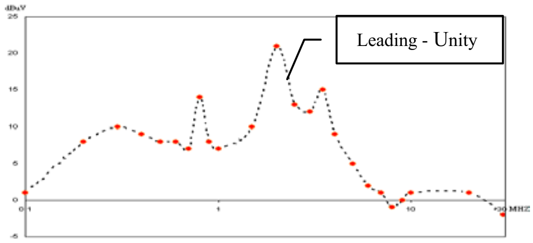

Figure 16 Comparison of leading and unity P.F.

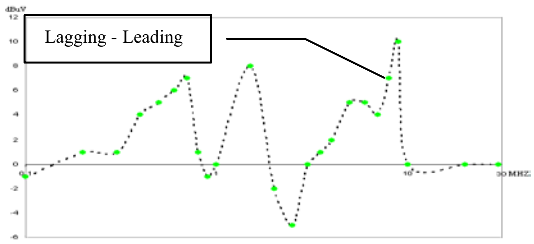

Figure 17 Comparison of lagging and leading P.F.

5. Discussion

The measured impedances results of each circuit that presented in table 2 can be modified by the transformed data as shown in table 3, which shows the difference values of each point compare with their previous point values by using equation 1. The different of impedance mismatch of point 1 comparing other points is the key criteria to estimate the EMI emission such as the unity power factor case has the smallest change in impedance variation of those four points comparing to both of leading and lagging power factor. This result is confirmed in table 3. The power transfer and power ratio of this circuit is presented in table 4 and 5 respectively. These results can also confirm the power loss in the circuit such as the maximum power loss of this circuit is the lagging power factor case, and minimum power loss is the unity power factor case. Some of their losses generate the EMI emission as shown in Figures 11-13. Figure 14 shows the envelope lines of EMI from Figures 11-13.

More contents can be discussed as follows:

1. The analysis of the relationship of the impedance mismatch and the conducted EMI emission and also compare of emission between lagging, leading and unity power factor are shown in Figures 15-17, EMI of unity power factor is lower than of those lagging and leading power factors during 150 kHz to 10 MHz, which shows the effect of differential-mode emission, that can support the mismatch impedance approach. For the frequency more than 10 MHz, the common-mode emission will be dominated; therefore, these results of all loaded power factor will generate the same EMI trend.

2. The impedance mismatch affect to the power transfer. The power transfer can also be presented and proved to support the conducted EMI emission trends of these three cases.

6. Conclusion

This paper proposes the process to analyze the conducted EMI emission using the impedance mismatch approach. Five steps of the process are describes. Some impedance fixtures and EMI measured results show how the relationship of impedance ratio and conducted EMI emission are occurred. The power flow can also support the prediction of EMI phenomena that can be complied for any complicating circuits.

7. References

[1] Sokal, N.O., Sokal, A.D., “ClassE-A New Class of High-Efficiency Tuned Single-Ended Switching Power Amplifiers”, IEEE J. Solid-State Circuits, vol. 10, no. 3, 1975, pp. 168-176.

[2] A. Jangwanitlert, V. Kinnares, T. Warit, Y. Rattiya. “A Class E ZVS Resonant Inverter for Induction Cooking.”,IPEC-Tokyo, pp. 1737-1740.