International Journal of Research in Engineering and Science (IJRES)
ISSN (Online): 2320-9364, ISSN (Print): 2320-9356
www.ijres.org Volume 3 Issue 2 ǁ Feb. 2015 ǁ PP.56-64

Design Topology of Low Profile Transformer forSlim Adaptor

Pankaj Rajbhoj, RajshreeSarwdnya
Instrumentation Enggdept S.G.G.S Institute of engg and Technology Nanded,India
Instrumentation Enggdept S.G.G.S Institute of engg and Technology Nanded,India

Abstract—This paper presents the implementation of a topologyfor low profile transformer using an LLC resonant converter. A new structure of the slim-type transformer is proposed, which is composed of copper wire as the primary winding and printed circuit-board winding on the outer layer as the secondary winding.The proposed circuit operates at high switching frequency to increase power density. The proposed structure is suitable for a slim and high-efficiency converter because it has advantages of easy utilization and wide conductive cross-sectional area. In addition, the voltage-doubler rectifier is applied to the secondary side due to its simple structure of secondary winding, and a CLC filter is adopted to reduce the output filter size.The specification are to design input voltage 400v,power 120w with 17ms hold time.

Index Terms—CLC output filter, voltage-doubler rectifier, LLC resonant converter,slim adaptor

I. INTRODUCTION

Over the past several years energy efficiency and power density have become the top concerns for power conversions. Rising energy intensity leads to a higher cost for delivering power.Meanwhile, the demand for compact power supplies grows significantly. It requires power supplies with high efficiency, low profile and high power density.With the development of information technology, computing system applications, such as telecom, server and computers, consumer electronics, such as flat-panel TVs and lighting systems, such as LED lamps, have become a large market for the power supply industry. Recent statistic data show that the demands for these systems are continuously increasing [3]

Moreover, because of the improving of integrated circuit technology, which follows Moores Law, computing systems and consumer electronics are continually increasing their density and functionality. The increasing functionality requires more power consumption and higher density requires less size on the power supplies. Therefore, the power supplies for thecomputing, consumer electronics and lighting applications are required to provide more power with small size and low cost.

Front-end converters are normally implemented by the twostageapproach, which includes a power factor correction (PFC) stage followed by a dc-dc stage. Therefore, laptop computers have become slim, and the adapter has been demanded to be slim and have high power rating accordingly. When the adapter is operated with high power level, it provides high

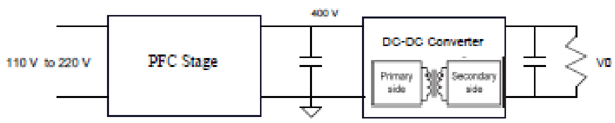

Fig. 1. Block diagram of Slim type Adaptor

power loss and heat [7]. Low operating temperature is one ofthe most important issues of adapter application; furthermore, it can be difficult to be achieved in the slim-type converter. Therefore, the high efficiency of the slim adapter is strongly required to reduce the power loss and operating heat. The boost converter has been adopted to the PFC stage generally due to its simple structure and high efficiency. [3]

II. TOPOLOGY FOR PRIMARY SIDE

LLC resonant converter is gaining attention because ofits ability to achieve higher frequencies and low switching losses .It consists of two inductors and one capacitor and the converter can regulate the output voltage against line and load variation over a wide range. Soft switching can be achieved over the entire operating range compared with LCC. In LLC configuration, the uncoupled inductor can be replaced by a coupled one so that the size of the converter can be reduced. the performance parameters such as output voltage ripple, switching losses,efficiency and voltage gain are computed. Simulation studies are carried out using MATLAB/SIMULINK. The advantage of LLC is achievement of ZVS even under no-load condition and narrow switching frequency at light load [1].fig 2 shows circuit for LLC resonant Converter.The DC characteristics of LLC(Inductor inductor Capacitance) resonantconverter could be divided into Zero Voltage

Switching (ZVS) region and Zero Current Switching (ZCS) region. For this converter, there are two resonant frequencies. One is determined by the resonant components Lrand Cr. The other one is determined by magnetizing inductance , resonant capacitance and load condition. The two resonant frequencies are given by

$$F_r1 = \frac{1}{2\Pi\sqrt{L_r C_r}} \quad (1)$$

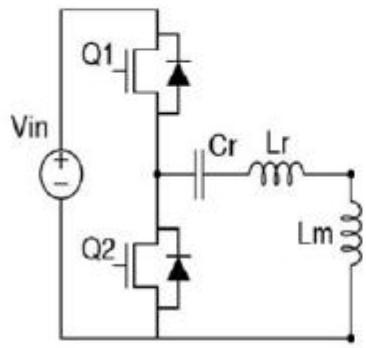

Fig. 2. LLC Resonant Converter

$$F_r2 = \frac{1}{2\pi\sqrt{L_m + L_r C_r}} \quad (2)$$

When LLC operates in ZVS condition, Lm never resonates with resonant capacitor Cr; it is clamped by output voltage and acts as the load of the series resonant tank. With this passive load, LLC resonant converter is able to operate at no load condition without the penalty of very high switching frequency. [5] Under ZCS operating region, the waveforms could be divided into two time intervals. In first time interval, Lrresonates with Cr. Lm is clamped by output voltage. When Lrcurrent resonates back to same level as Lm current, the resonance of Lr and Cr is stopped, instead, now Lm will participate into the resonance and the second time interval begins. During this time interval, the resonant components will change to Cr and Lm in series with Lr. The operation of LLC resonant converter is divided into three modes namely mode 1, mode 2, mode 3.

A. Mode 1

Begins when Q2 is turned off at t0. At this moment, resonant inductor Lrcurrent is negative; it will flow through body diode of Q1, which creates a ZVS condition for Q1. Gate signal of Q1 should be applied during this mode. When resonant inductorLrcurrent flow through body diode of Q1, ILrbeginst0 rise, this will force secondary diode D1 to conduct and I0begin to increase. Also, from this moment, transformer sees output voltage on the secondary side. Lm is charged with constant voltage.

B. Mode 2

Begins when resonant inductor current ILrbecomes positive. Since Q1 is turned on during mode 1, current will flow through MOSFET Q1. During this mode, output rectifier diode D1 conduct. The transformer voltage is clamped at V0. Lm is linearly charged with output voltage, so it doesn't participate in the resonant during this period. In this mode, the circuit works like a SRC with resonant inductor Lrand resonant capacitor Cr. This mode endswhen Lr current is the same as Lm current. Output current reach zero.

C. Mode 3

The two inductors currents are equal.Output current reach zero. Both output rectifier diodes D1 and D2 is reverse biased.Transformer secondary voltage is lower than output voltage. During this period, a resonanttank of Lm in series with Lrresonates with Cr. This mode ends when Q1 is turned off. To meet the increasing stringent requirement of high efficiency and high power density, improvement of dc-dc conversion technology over wide input voltage range is a must.Therefore, this dissertation mainly focuses on the investigation of novel techniques to improve the overall performance of front-end dc-dc converters with wide input voltage range operation. The leakage reactance is very important parameter in LLC resonant Converter because its directly related to resonance. And it is calculated by distance between primary and secondary winding so its not required any external resonant inductor. [8] ZVS capability from the zero load to the full load and low turn-off current for primary side switches, so switching loss is low.Zero-current-switching (ZCS) is achieved for secondary side rectifiers and low voltage stress and High voltage gain capability, which is suitable for holdup time operation, and means that bulky capacitors can be reduced considerably.

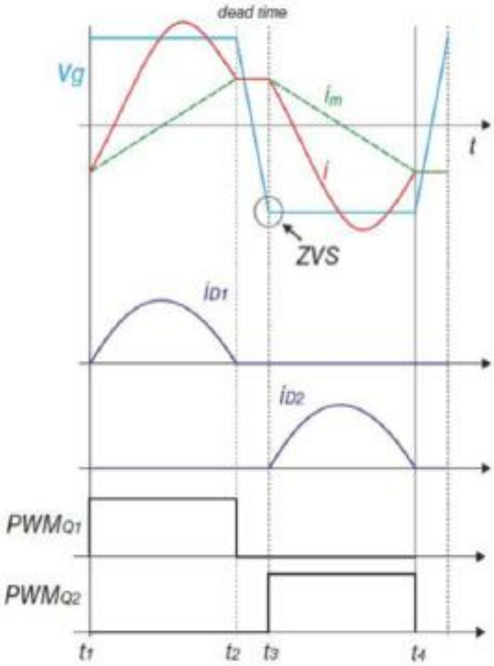

Fig. 3. LLC resonant converter waveforms at resonant frequency

soft switching means the one or more power switches in a dc-dc converter have either turn ON or turn OFF switching loses eliminated.The inductive character of the resonant frequency allows to achieve zero voltage switching(ZVS), which is preferred for MOSFET transistors.LLC Resonant Converters can achieve ZVS for Primary side devices and ZCS for secondary side devices.Switching transitions occur under favourable conditions device voltage or current is zero.Allowsthe operation at a higher frequency and at higher input voltages without sacrificing efficiency.it eliminates diode reverse recovery effects.it can be operate without snubber.

III. TOPOLOGY OF SECONDARY SIDE

Topology selection of secondary is important to build a highefficiency and slim type converter.
Selection of topology secondary side:

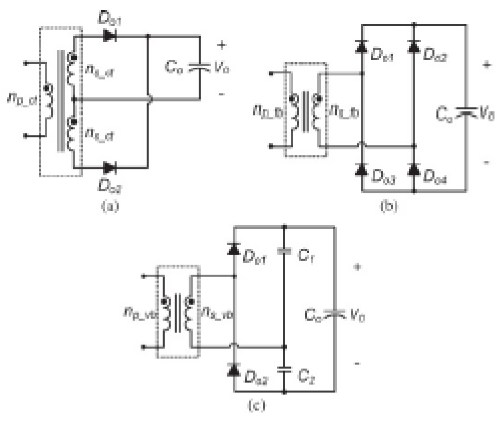

Fig. 4. (a) center tapped (b) Full bridge (c) Voltage doubler

Center-tapped, full bridge and voltage doubler are topologiesfor secondary side. The configuration of secondary side of transformer is very difficult to design due to large current on secondary side and its large current flow on secondary side and its required wide conductive area. In full bridge is obtain same conversion ratio. Although the center tapped configuration needs to different secondary winding so it is not appropriate for transformer because of it is complex structure of secondary side. Hence the voltage doubler rectifier can be selected for the secondary side with just one turn in the secondary winding. In the operating condition,in meanwhile the capacitor output filter is adapted,because the current flowing output capacitance is discontinued,so the rms ripple current of output capacitance is very large,for that bulky capacitor are needed to overcome
it.

A. Voltage doubler with CLC output filter

For reduce the output filter size and large ripple currentin that case,a CLC filter is used. due to small inductor,largecurrent ripple is generated in the left side of capacitor Cfand ripple current right side capacitor C0 is small. [9]

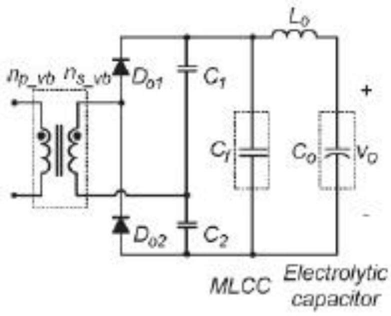

Fig. 5. voltage-doubler rectifier with CLC output filter

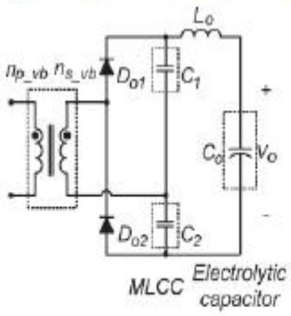

Fig. 6. simplified voltage-doubler rectifier with CLC output filter.

The electrolytic capacitor is applied to C0 since it has large capacitance value with the voltage doubler,using the CLC filter.its already having two capacitor C1and C2.so only small inductor is needed to complete the CLC filter configuration.

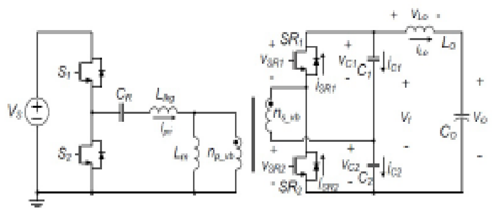

Fig. 7. Circuit diagram of LLC resonant converter with voltage-doubler rectifier and CLC output filter.

IV. DESIGN OF TOPOLOGY

A. Define the system specifications Estimated efficiency (Eff) Input voltage range: hold up time should be considered for minimum input voltage [2]

$$V_{in}min = \sqrt{V_{0.PFC}^2 - \frac{P_{in}T_{HU}}{C_{DL}}} \qquad (3)$$

$$P_{in} = \frac{P_0}{eff} \qquad (4)$$

$$V_{in}min = \sqrt{V_{0.PFC}^2 - \frac{P_{in}T_{HU}}{C_{DL}}} \qquad (5)$$

$$V_{in}min = \sqrt{400^2 - \frac{2*123*17*10{-}3}{100*10{-}6}} = 343v \qquad (6)$$

$$V_{in}max = V_{0.PFC} = 400v \qquad (7)$$

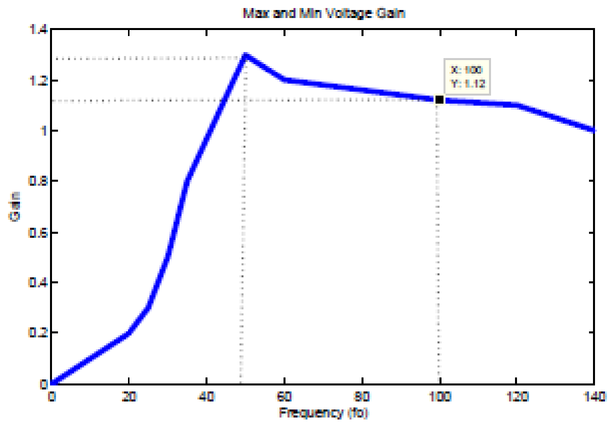

Fig. 8. Minimum and Maximum Voltage Gain

B. Determine the maximum and minimum voltage gains of the resonant network by choosing K it is typical to set K to be 5 - 10, which results in a gain of 1:1-1:2 at f0 where K is coefficient. where M is Voltage Gain

$$Mmin = \frac{V_{R0}}{\frac{V_{in}max}{2}} = \frac{L_m + (n^2)L_{lks}}{L_m} = \frac{L_m + L_{lkp}}{L_m} = \frac{K+1}{K} \qquad (8)$$

$$Mmax = \frac{V_{in}max}{V_{in}min} * Mmin \qquad (9)$$

In design example, The ratio (k) between Lm and Llkpis determined as 8,which result in the min gain as,

$$Mmin = \frac{V_{R0}}{\frac{V_{in}max}{2}} = \frac{K+1}{K} = 1.12 \qquad (10)$$

$$Mmax = \frac{V_{in}max}{V_{in}min} * Mmin = 1.30 \qquad (11)$$

C. Determine the transformer turns ratio

$$n = \frac{N_p}{N_s} = \frac{V_{in}max}{2(V_0 + V_f)} * Mmin$$
$$= 12 \qquad (12)$$

D. Calculate the equivalent load resistance (Rac)

$$Rac = \frac{8(n)^2}{\pi^2}\frac{V_0^2}{P_0max} \qquad = 294\Omega \qquad (13)$$

E. Design the resonant network

With k chosen in STEP-2, read proper Q from gain curves
K=8, M max=1.30
Peak Gain=1.30*110% =1.43

As Calculated in step 2 the maximum voltage gain(M max)for the minimum input voltage(Vin max)is 1.30 with 10% margin,a peak gain of 1.43 is required k has been chosen as 8 in step 2 and Q is obtain o.4 from peak gain curves.by selecting the resonant frequency as 100kHz the resonant components are

$$C_r = \frac{1}{2\pi Q F_0 Rac} \qquad = 13.5nF \qquad (14)$$

$$L_r = \frac{1}{(2\pi F_0)^2 C_r} \qquad = 187\mu H \qquad (15)$$

$$L_p = \frac{(k+1)^2}{(2k+1)} L_r \qquad = 891\mu H \qquad (16)$$

$$F_r = \frac{1}{2\pi\sqrt{L_r C_r}} \qquad = 100kHz \qquad (17)$$

$$F_s = \frac{1}{2\pi\sqrt{L_p C_r}} \qquad = 47kHz \qquad (18)$$

$$L_p = L_r + L_m = 704\mu H \qquad (19)$$

$$T_r = \frac{1}{F_r} = 0.00001s \qquad (20)$$

$$T_s = \frac{1}{F_s} = 2.12 * 10^-5s \qquad (21)$$

$$F_n = \frac{f_s}{f_r} = 0.47s \qquad (22)$$

Adopting the voltage doubler rectifier on the secondary sidewith only one turn so it is easy to design a PCB trace winding on secondary side.hence it would be very simple structure and also maximum losses are minimised. CLC filter is used to reduce the ripple current of the output capacitance with the assumption that the capacitance C0 is large enough so that the output voltage ripple can be neglected so only filter inductor L0 and doubler capacitors C1 and C2 are in the circuit. [3]

Calculation of Ripple current:

$$\Delta i_{L0}(t_0 - t_1) = \frac{1}{L_0}\int_{t_0}^{t_1} V_{L0}(t)dt \qquad (23)$$
$$= \frac{T_R}{4L_0C_s} I_0(\frac{T_s}{\pi} - \frac{T_R}{4})$$

$$\Delta i_{L0}(t_1 - t_2) = \frac{1}{L_0}\int_{t_1}^{t_2} V_{L0}(t)dt \qquad (24)$$
$$= \frac{I_0}{L_0C_s}(\frac{T_R^2}{16} + \frac{T_s^2}{16} - \frac{T_RT_S}{8})$$

Therefore,the output ripple current can be expressed as follows:

$$\Delta I_{L0} = \Delta i_{L0}(t_0 - t_1) + \Delta i_{L0}(t_1 - t_2)$$
$$\Delta I_{L0} = \frac{I_0}{L_0C_s}(\frac{T_s^2}{16} + \frac{T_sT_R}{4\pi} - \frac{T_sT_R}{8}) \qquad (25)$$

Output Voltage Ripple:

$$V_{ripple} = V_{max} - \frac{V_{min}}{V_{avg}} \qquad (26)$$

TABLE I
DESIGN PARAMETERS OF LLC RESONANT CONVERTER

Parameter	Designator	Value
input value	V_{in}	400
resonant Inductor	L_r	$187\mu H$
resonant Capacitor	C_r	13.5nf
Magnetising Inductor	L_m	$704\mu H$
Resonant Frequecy	F_r	100kHz
Switching Frequecy	F_s	47kHz
Turn ratio	N_n	12

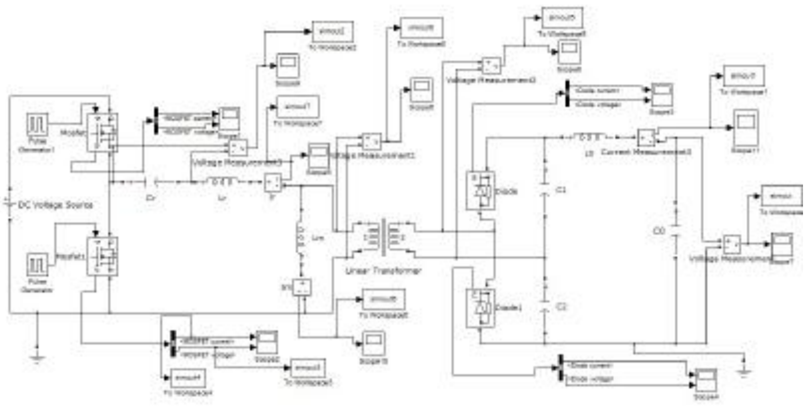

Fig. 9. Simulation Ciruit of LLC resonant converter with voltage-doubler rectifier and CLC output filter.

V. CIRCUIT SIMULATION AND RESULTS

from the above calculations of The parameters of theconverter the input voltage VS =400 V, output voltage V0= 18 V,turns ratio npvd : nsvd = 12, switching frequency FS =47 kHz, leakage inductance Lr = 187_H, magnetizing inductance Lm = 704_H, resonant capacitance CR = 13.5nF,doubler capacitance C1 = C2 = 1000_F, output filter inductance L0 = 5e □ 7H, and output filter capacitance Co = 4700_F.Simulation Circuit shown in Fig.9 and Fig 10 to Fig.13 shows the outputs of the Low profile Transformer by using various topology.

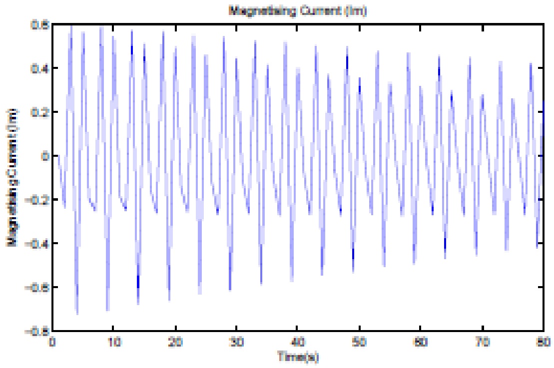

Fig. 10. Magnetising Inductor Current

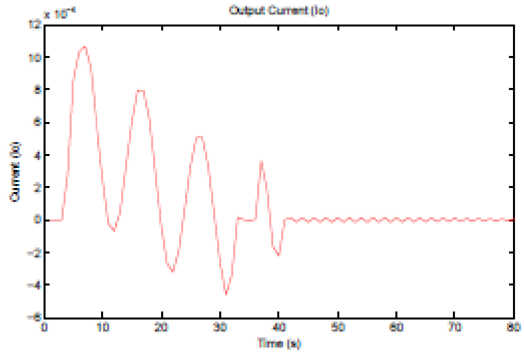

Fig. 11. Output Current

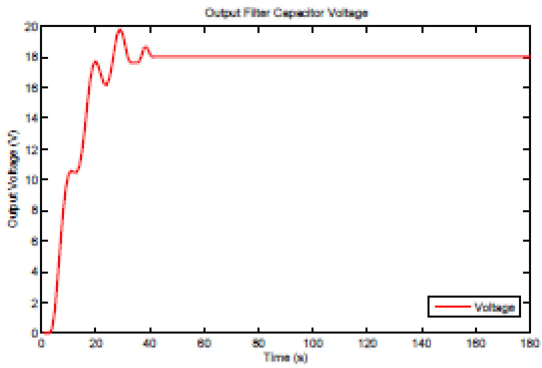

Fig. 12. Output Voltage

VI. CONCLUSION

The LLC resonant converter and voltage doubler rectifierare applied to the topologies of the primary and the secondary side. The secondary side of the transformer can be simplified with this configuration, and the effective PCB winding of the secondary side can be achieved easily. its having easy utilization and wide conductive cross-sectional area. Also, the output filter size can be reduced using the CLC filter, and it is suitable for the voltage-doubler rectifier since just the small filter inductor is added.So,using various topologies the losses will be minimized and efficiency will be Increase. As shown all the output parameters that are meets required specification.

REFERENCES

[1] M. Shaik and R. Kankanala, “Digital compensator design for llc resonant converter,” Microchip Technology Inc. DS01477A, 2012.

[2] S. Abdel-Rahman, “Resonant llcconverter :operation and design 250w 33vin 400vout design example,” Infine on Technologies North America(IFNA)Corp., vol. 1.0, September-2012.

[3] D.-Y. Kim, C.-E.Kim and G.-W. Moon, “High-efficiency slim adapter with low-profile transformer structure,” IEEE TRANSACTIONS ON INDUSTRIAL ELECTRONICS, vol. 59, no. 9, pp. 3445–3448, SEPTEMBER 2012.

[4] W. G.Hurley and D. J.Wilcox, “Calculation of leakage inductance in transformer windings,” IEEE TRANSACTIONS ON POWER ELECTRONICS, vol. 9, no. 1, pp. 121–126, JAN 1994.

[5] P. Chandrasekhar and S. R. Reddy, “Design consideration of llc resonant converter for electrolyser,” International Journal on Electrical Engineering and Informatics, vol. 3, no. 3, pp. 278–291, 2011.

[6] Dr.R.Seyezhai, G.Ramathilagam, and P. Chitra, “Investigation of halfbridgellc resonant dcdc converter for photovoltaic applications,” International Journal on Electrical Engineering and Informatics, vol. 1, no. 3, pp. 76–81, June 2013.

[7] V. N, N. K. D, and U. M. T, “Low power devices for an electronic adapter with mitigating the soft errors,” IOSR Journal of Electrical and Electronics Engineering, vol. 9, no. 2, pp. 20–27, Apr 2014.

[8] D. Fu, Topology Investigation and System Optimization of Resonant Converters. PhD thesis, Dept. of Electrical Engg., Virginia Polytechnic Institute and State University,Virginia, 2010.

[9] W. Chen, Y. Yan, and Y. Hu, “Model and design of pcb parallel winding for planar transformer,” IEEE TRANSACTIONS ON MAGNETICS, vol. 39, no. 5, pp. 3202–3204, SEPTEMBER 2003.

[10] B. Theraja and A.K.Theraja, A Textbook Of Electrical Technology AC and DC Machines. S Chand.

[11] MatLab/Simulink Control Design Toolbox user manual. ver. 3, 2012