Flyback Transformer Modelling

Farzin Asadi[*,1], Nurettin Abut[2]

[1]: Mechatronics engineering department, Kocaeli university, Kocaeli, Turkey.

[2]: Electrical engineering department, Kocaeli university, Kocaeli, Turkey.

{farzin.asadi@kocaeli.edu.tr}

Abstract:

Providing the required load power using Switch Mode Power Supplies (SMPS), leads to smaller and more efficient converters. Flyback converter is one of the most famous topologies in use. Flyback converter is equivalent to buck-boost converter with the inductor split to form a transformer. The operating principle of two converter is very similar. Both transfer energy to the load when switch is in off state. Also, both suffer from Right Half Plane (RHP) zero when operating in Continuous Conduction Mode (CCM). Flyback transformer is the most important part of flyback converter. This paper develops a software package to model the flyback transformer based on simple measurements. Developed software solves a set of nonlinear equations to obtain the model parameters. Designing of snubber circuit can be done based on the obtained model. Developed software is free of charge. Contact authors to receive the software.

Keywords: Flyback converter, flyback transformer, leakage inductances, modeling.

Introduction:

Flyback converter (Fig. 1) is one of the most useful converters. It can be used for both AC/DC and DC/DC conversion. Flyback topology can provide galvanic isolation between the inputs and outputs. Like other converters Flyback converter can work in Continuous Conduction Mode (CCM) or Discontinuous conduction modes (DCM).Table 1, list the disadvantages of these two modes:

Table1: Disadvantages of CCM and DCM Flyback converter.

CCM Flyback	DCM Flayback
■ Precense of a right half plane zero in the response of converter decreases voltage feedback loop bandwidth. ■ Current mode control needs slope compensation when duty cycle is greater than 50%. ■ Turning on the power switch take place with positive current flow. So, in addition to turn off speed, turn on speed is important.	■ RMS and peak currents are high ■ High flux excursion in the inductor

Schematic of a Flyback converter is shown in Fig. 1:

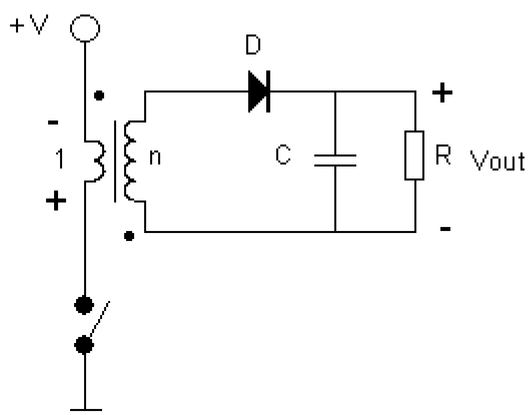

Figure 1: Schematic of a flyback converter.

While it is common to show a transformer in circuit diagram, generally a coupled inductor is used instead of a transformer. Coupled inductor stores the income energy in the air gap. When switch is turned off the stored energy is transferred to the load. Transformer is a device which transfers energy instantaneously, i.e. without delay, from input to output ends. Transformers are not designed for storing energy. Although, using “Flyback transformer” term is common in literature, a coupled inductor is intended. Modeling a flyback transformer is an important issue. Flyback transformer’s leakage inductances cause voltage overshoot. Effect of these leakage inductances on circuit performance can be studied with a circuit simulator program. This paper introduces a method for modeling flyback transformer. This paper introduces a software package for modeling flyback transformers. This paper is organized as follows: Method is introduced in the second section. A toolbox is developed to automate the calculations in the third section. Finally, laboratory test results are given and suitable conclusions are drawn.

Method:

Assume a flyback transformer that has one primary winding and two secondary windings. Generally one of the outputs is the main output, i.e. providing load power and one is used for cooling purposes, i.e. rotating a fan which cools heat sinks, or control purposes.

Using elementary circuit analysis, the model shown in Fig. 2, is suggested for three winding flyback transformer.

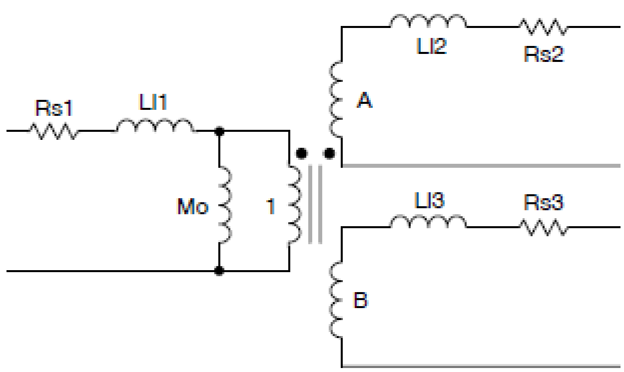

Figure 2: Model of 3 winding flyback transformer.

As shown in Fig. 2, there are four inductances available in this model. So, four independent equations are required to calculate these inductances. Assume that, frequency is high enough so wire resistance is negligible with respect to inductor reactance. Injecting a sinusoidal voltage v_p to primary and measuring the open circuit output voltages on secondary's ($v_{s,power}$ and $v_{s,auxiliary}$) one can find the turn ratio as:

$$A = \frac{v_{s,power}}{v_p} \text{ and } B = \frac{v_{s,auxiliary}}{v_p} \qquad (5)$$

Where A is turn ratio of main output and B is the turn ratio of auxiliary output. Four equations are required for inductance calculations. Assume that L_1 is the inductance seen from primary side when two secondaries are open. L_2 is the inductance seen from primary with power winding open, auxiliary shorted. L_3 is the inductance seen from primary with power winding shorted and auxiliary winding open. L_4 is the inductance seen from power winding with auxiliary shorted and open primary.

Relation between L_1,L_2,L_3,L_4 and leakage inductances are given below:

$$L_1 = L_{l1} + M_o \qquad (1)$$

$$L_2 = L_{l2} + \frac{M_o.\frac{L_{l3}}{B^2}}{M_o + \frac{L_{l3}}{B^2}} \qquad (2)$$

$$L_3 = L_{l1} + \frac{M_o.\frac{L_{l2}}{A^2}}{M_o + \frac{L_{l2}}{A^2}} \qquad (3)$$

$$L_4 = L_{l2} + A^2\frac{M_o.\frac{L_{l3}}{B^2}}{M_o + \frac{L_{l3}}{B^2}} \qquad (4)$$

These nonlinear equations must be solved to obtain theL_{l1},L_{l2},L_{l3}, M_o. Developed software do this job.

Model of a transformer with one primary and one secondary is shown in Fig. 3.

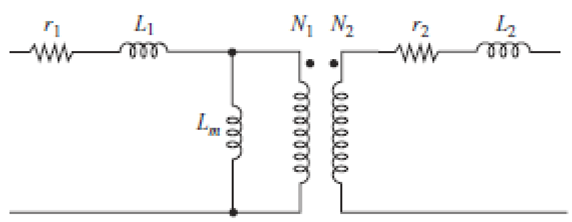

Figure 3: Model of 2 winding transformer.

Parameters of this model can be calculated using three measurements: $L_{p(open)}$, which is the primary winding inductance with open secondary, $L_{p(short)}$, that is primary winding inductance with shorted secondary and $N = \frac{N_1}{N_2} = \frac{v_{primary}}{v_{secondary}}$, which is turn ratio. Using these measurements, one can find L_1, L_2 and L_m as follows:

$$L_1 = (1-k).L_{p,open} \qquad (6)$$

$$L_2 = (1-k).L_{p,open} \cdot \frac{1}{N^2} \qquad (7)$$

$$L_m = k.L_{p,open} \qquad (9)$$

Where:

$$k = \sqrt{1 - \frac{L_{p,short}}{L_{p,open}}} \qquad (10)$$

Applying the aforementioned procedure to a flyback transformer with and $N = \frac{v_{primary}}{v_{secondary}} = \frac{1}{.469} = 2.13$, $L_{p(open)}$= 352.8 µH, $L_{p(short)}$= 24.45 µH, leads to $k = 0.965$, $L_{l1} = 12.35$ µH and $L_{l2} = 2.72$ µH.

Developed software:

Fig. 4, shows the developed software, user only enter L1,L2,L3 and L4. Software solves the nonlinear equations and gives L_{l1},L_{l2} and M_o.

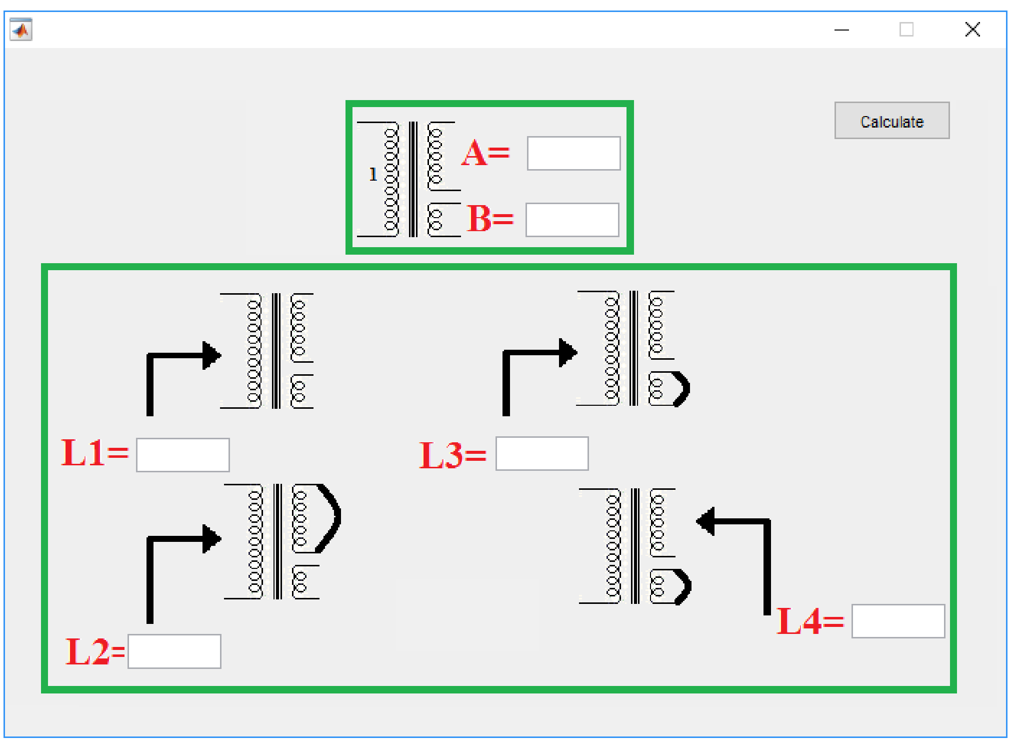

Figure 4: Developed software.

Laboratory tests:

L1,L2,L3 and L4 are measured with the aid of a precious RLC meter (Fig. 5). Measurements are done at 100 KHz.

Figure 5: Precious RLM meter used for measurements.

Figure 6: Undertest flyback transformer.

Using aforementioned procedure, following numbers are obtained:

$$A = 0.99, \qquad (11\text{-}1)$$

$$B = 0.484, \qquad (11\text{-}2)$$

$$L_1 = 1541.8\mu H, \qquad (11\text{-}3)$$

$$L_2 = 72.070\mu H, \qquad (11\text{-}4)$$

$$L_3 = 57.430\mu H, \qquad (11\text{-}5)$$

$$L_4 = 82.804\mu H. \qquad (11\text{-}6)$$

After entering these numbers to the developed software,

$$L_{l1} = 22.91\mu H, \qquad (12\text{-}1)$$

$$L_{l2} = 34.62\mu H, \qquad (12\text{-}2)$$

$$L_{l3} = 11.90\mu H, \qquad (12\text{-}3)$$

$$M_o = 1500\mu H, \qquad (12\text{-}4)$$

Conclusion:

Flyback converter is one of the most important topologies in use. Flyback transformer is the heart of flyback topology. This paper introduced a software package for modeling problem of flyback transformer. Obtained model can be used for simulation purposes and designing the snubber circuits.

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