REAL-TIME SIMULATION OF DC-DC FLYBACK CONVERTER USING FSS MINI

Haridas M S
P G student
Department of Electrical Engineering
Rajiv Gandhi Institute Of Technology
(Govt. Engineering College), Kottayam
Email:haridasmsrit@gmail.com

Dr.Prince A
Associate Professor
Department of Electrical Engineering
Rajiv Gandhi Institute Of Technology
(Govt. Engineering College), Kottayam
Email:princearattupuzha@gmail.com

***Abstract*— Simulation is an extremely valuable tool for designing, operating and understanding complex systems in Power systems and Power Electronics. Broadly simulation can be of two types, Off-line and Real-time Simulation. Off-line simulation uses a digital computer and real time simulation uses a dedicated high speed digital processing hardware. Real time simulation allows analysis of a physical system in real-time. Full Spectrum Simulator (FSS) provides both off-line and real-time simulation capabilities at an affordable cost, easily configurable for custom applications. FSS is useful for real-time simulation of large power systems and power electronic equipments. Applications of real-time simulation includes training and demonstration of power electronic systems, closed loop testing of power subsystem protective relays, evaluation of control hardware and software and testing of high power systems like FACTS devices, Custom Power devices, AC/DC motor drives etc.**

The paper deals with simulation of a DC-DC flyback converter in real-time using FSS Mini. For real-time simulation using FSS, the main objective was to create an average model of the flyback converter in CCM mode of operation. Average model was derived from the circuit equations and designed the values of the parameters used in the averaged model. Simulation using MATLAB was done first and obtained the output voltage waveform. Same equations were used for creating the library element in the real-time simulation library. Then it was simulated using FSS and obtained the real-time simulation output in a DSO.

Keywords—Real time Simulation, DC-DC Flyback Converter, Average Modelling, FSS.

I. INTRODUCTION

Flyback converter is found in most of the applications in consumer products as compared to other switching converter topologies below 200 watts. This includes compact fluorescent light DVD player, mobile chargers, notebook and Laptop chargers etc. Isolated and nonisolated switching converters are equally popular in commercial application like laptops, SMPS of personal computers, DC drives, communication equipments, portable devices, and other domestic and office equipments. Isolated switching converters are preferred where multiple outputs, load protection, reduce noise interference and more output power is required. It is also useful in the situation where the polarity reversal, step-up and step-down procedure is needed. Usually flyback converter and other switching converters are implemented with PWM control methods.

Real-time simulation as the name suggests, allows analysis of physical systems in real-time.In real-time simulation the physical time and the simulation time are the same. This helps greatly in conducting hardware in the loop simulation and evaluation of control hardware and software. FSS is useful for Real-time simulation of large power system and power electronics equipments.

II. TYPES OF SIMULATION

Broadly, simulation can be of two types:

A. *Off-Line Simulation*

Off-line simulation generally carried out with standard software packages such as Simulink , SABER etc, allows flexibility in analysing a wide variety of components and systems. Commercial simulators that are powerful enough to tackle complex problems are expensive in the indian context. Furthur,they come with a limited number of licences. Also, component libraries in these simulators are encrypted, and so are not available to the user for viewing or modification. Updates and support services are also costly.

For digital simulation it is assumed that a simulation with discrete-time and constant step duration is performed. During discrete-time simulation, time moves forward in steps of equal duration. This is commonly known as fixed time-step simulation. It is important to note that other solving techniques exist that use variable time-steps. Such techniques are used for solving high frequency dynamics and non-linear systems, but are unsuitable for real-time simulation. To solve mathematical functions and equations at a given time-step, each variable or system state is solved successively as a function of variables and states at the end of the proceeding time-step.

During a discrete time simulation, the amount of real time required to compute all equations and functions representing a system during a given time-step may be shorter or longer than the duration of the simulation time step as shown in Figure.1 & Figure.2. In Figure.1, the computing time is shorter than the fixed time-step (also referred to as accelerated simulation) while in Figure.2 the computing time is longer. These two situations are referred to as offline simulation. In both cases, the moment at which a result becomes available is irrelevant. Typically, when performing offline simulation, the objective is to obtain results as fast as possible. The system solving speed depends on available computation power and the system's mathematical model complexity.

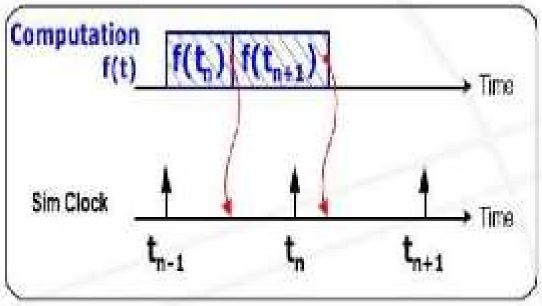

Figure.1: Offline Simulation-Faster than Real Time

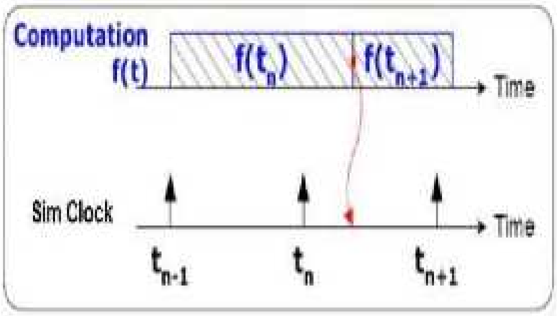

Figure.2: Offline Simulation-Slower than Real Time

B. Real-Time Simulation

During real-time simulation, the accuracy of computations not only depends upon precise dynamic representation of the system, but also on the length of time used to produce results as shown in Figure.3 For a real-time simulation to be valid, the real-time simulator used must accurately produce the internal variables and outputs of the simulation within the same length of time that its physical counterpart would. In fact, the time required to compute the solution at a given time-step must be shorter than the wall clock duration of the time-step. This permits the real-time simulator to perform all operations necessary to make a real time simulation relevant, including driving inputs and outputs (I/O) to and from externally connected devices. For a given time-step, any idle-time preceding or following simulator operations is lost; as opposed to accelerated simulation, where idle time is used to compute the equations at the next time-step. In such a case, the simulator waits until the clock ticks to the next time step. However, if simulator operations are not at all achieved within the required fixed time-step, the real-time simulation is considered erroneous. This is commonly known as an “overrun”. Based on these basic definitions, it can be concluded that a real-time simulator is performing as expected if the equations and states of the simulated system are solved accurately, with an acceptable resemblance to its physical counterpart, without the occurrence of overruns.

Real-time digital simulation is based on discrete time-steps where the simulator solves model equations successively. Proper time-step duration must be determined to accurately represent system frequency response upto the fastest transient of interest. Simulation results can be validated when the simulator achieves real-time without overruns. For each time-step, the simulator executes the same series of tasks:

- Read inputs and generate outputs.
- Solve model equations.
- Exchange results with other simulation nodes.
- Wait for the start of the next step.

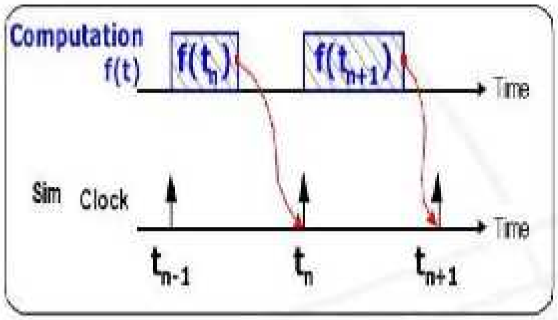

Figure.3: Real Time Simulation-Synchronised

III. DC-DC FLYBACK CONVERTER

Fly-back converter is the most commonly used SMPS circuit for low output power applications where the output voltage needs to be isolated from the input main supply. The output power of fly-back type SMPS circuits may vary from few watts to less than 100 watts. The overall circuit topology of this converter is considerably simpler than other SMPS circuits. Input to the circuit is generally unregulated dc voltage obtained by rectifying the utility ac voltage followed by a simple capacitor filter. The circuit can offer single or multiple isolated output voltages and can operate over wide range of input voltage variation. In respect of energy-efficiency, fly-back power supplies are inferior to many other SMPS circuits but its simple topology and low cost makes it popular in low output power range. The commonly used fly-back converter requires a single controllable switch like, MOSFET and the usual switching frequency is in the range of 100 kHz. A two switch topology exists that offers better energy efficiency and less voltage stress across the switches but costs more and the circuit complexity also increases slightly.

A. Circuit Description

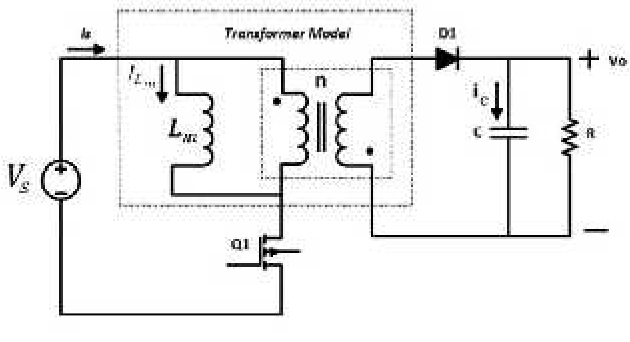

Figure.4: Circuit Diagram of DC-DC Flyback Converter

A simple circuit model of second order flyback converter is shown in Figure.4. This circuit includes a transformer with L_m magnetizing inductance as equivalent primary side inductance, transformer turn ratio ’n’, transistor switch Q_1 and input DC voltage is designated as V_s at primary side. Whereas at secondary side a diode D_1, output filter capacitor C and load resistor R are attached. As output is taken across the load so capacitor voltage is equal to output voltage. It is basically an isolated switching converter and a modified version of buck boost converter with transformer isolation. The waveforms of inductor voltage, capacitor current and input current for the flyback converter considering in continuous conduction mode are shown in Figure.5.

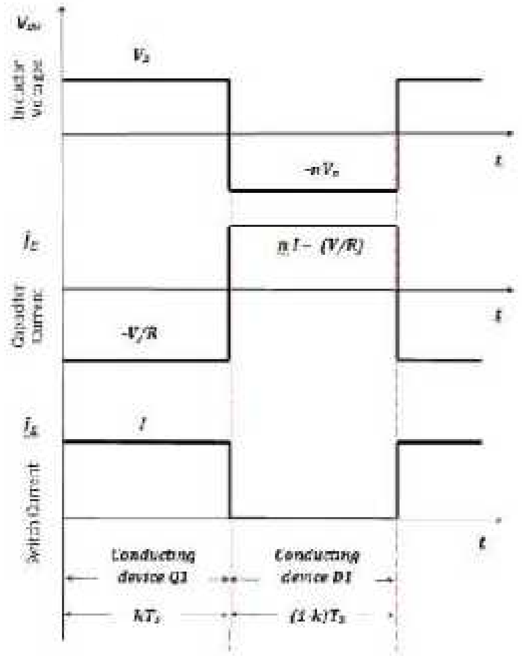

Figure.5: Waveform of DC-DC Flyback Converter

B. Operation Principle

When switch Q_1 is ON and primary side conducts, secondary side of transformer is open circuit in this phase due to reverse bias of diode D_1. All the energy from source V_s is stored in magnetizing inductance L_m, whilst output capacitor C contributes to deliver its stored energy to the load.

When Q_1 is OFF due to switching frequency and D_1 is ON so secondary side conducts in this phase. All the stored energy in magnetizing inductance is delivered to charge output capacitor C as well as to drive the load.

IV. AVERAGE MODELLING

If the duty cycle of switching frequency is 'k' then equations related to both the phases of flyback operation are given as;

when switch $Q_1 = \mathrm{ON}$ for time $(0 \le t \le k.T_s)$

$$\frac{dV_c}{dt} = \frac{-V_c}{C} \quad (1)$$

$$\frac{dI_{L_m}}{dt} = \frac{V_s}{L_m} \quad (2)$$

when switch $Q_1 = \mathrm{OFF}$ for time $(k.T_s \le t \le T_s)$

$$\frac{dV_c}{dt} = \frac{n\,I_{L_m}}{C} - \frac{V_c}{C} \quad (3)$$

$$\frac{dI_{L_m}}{dt} = \frac{-n\,V_c}{L_m} \quad (4)$$

for time $0 \le t \le T_s$

Averaging equations (1) and (3) , we get

$$\frac{dI_{L_m}}{dt} = (\ 0 \,.\, I_{L_m}) - \frac{n(1-k)}{L_m} V_c + \frac{V_s k}{L_m} \quad (5)$$

Averaging equations (2) and (4) , we get

$$\frac{dV_c}{dt} = \frac{n(1-k)}{C} I_{L_m} - \frac{1}{C} V_c \quad (6)$$

Equations (5) and (6) is used for creating the averaged circuit model. From the above equations the parameters to be designed are: n , R , C and L_m

V. DESIGN PARAMETERS

$V_s = 12$ V , $V_0 = 24$ V , k = 0.5, R=10Ω, f = 100 kHz

Transformer Turns Ratio,

$$n = \frac{k\,V_s}{V_0(1-k)} \quad (7)$$

Average magnetizing inductance current,

$$I_{L_m} = \frac{(V_0)^2}{V_s\,k\,R} \quad (8)$$

$$\Delta I_{L_m} = 40\%\ O\ I_{L_m} \quad (9)$$

Magnetizing Inductance,

$$L_m = \frac{k\,V_s}{\Delta I_{L_m} f} \quad (10)$$

Output Voltage Ripple, $\Delta V_0 = 2\%\ O\ V_0$ (11)

Output Capacitor, $C = \dfrac{V_0\,k}{f\,R\,\Delta V_0}$ (12)

Design Parameters	
V_s (input voltage)	12 V
V_0(output voltage)	24 V
L (inductor)	16µH
C(capacitor)	25µF
R(resistor)	10Ω

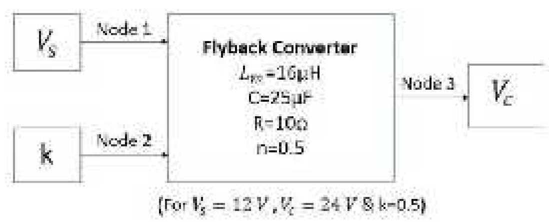

Figure.6: A Flyback Converter with constant Duty cycle

VI. MATLAB SIMULATION AND RESULTS

This section deals with the simulation of DC-DC flyback converter. Figure.7 shows the MATLAB simulation model of DC-DC Flyback converter. Figure.8 shows the MATLAB simulation output voltage waveform.

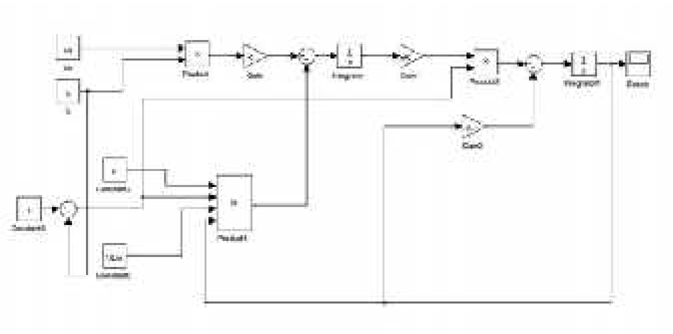

Figure 7: simulation model of DC-DC Flyback converter

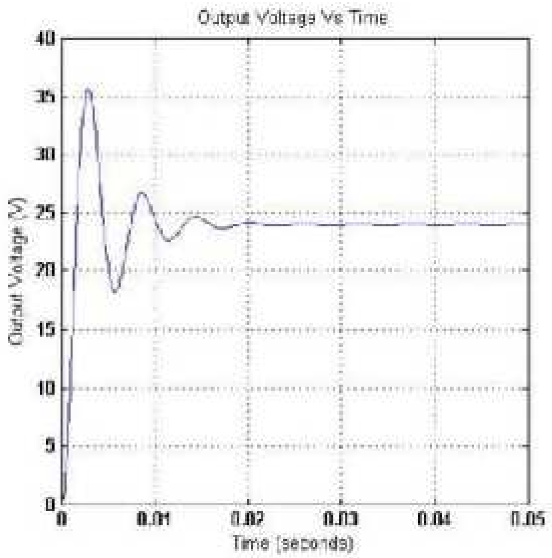

Figure.8: output voltage waveform

VII. EXPERIMENTAL SETUP

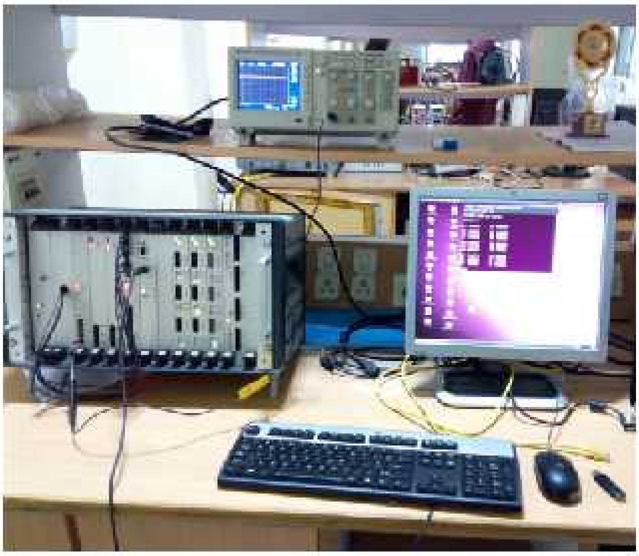

Figure.9: Experimental setup

The real-time library element of DC DC flyback converter is created and is loaded into FSS. For the real-time simulation of DC DC flyback converter, Miniature - Full Spectrum Simulator,FSS Mini-004 is used. The model number of the FSS used is **'DUM PE 107 0001'**. A linux operating system based PC is used for creating the library element and the circuit file. Binary file is generated after the pre-processing in the PC. The binary file is downloaded into the FSS through usb link in the system interface card. By using the IRC DSP access commands and CPU card commands the binary file is loaded into the corresponding DSP. The output is taken from the analog output card of FSS. The output waveform is plotted with the help of a Digital Storage Oscilloscope (DSO).

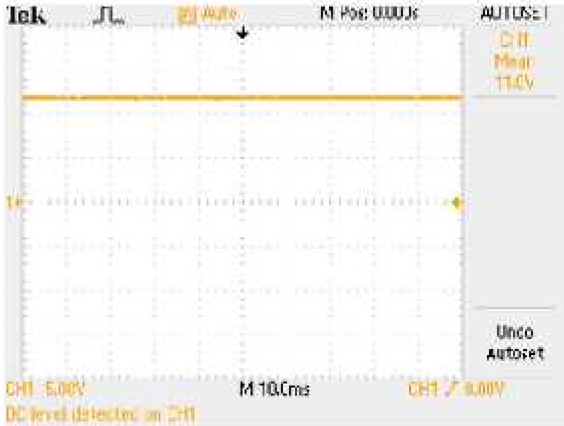

Figure.10: output voltage waveform obtained from FSS mini

Figure.10 shows the Output voltage signal obtained from FSS Mini.The mean output voltage obtained in DSO is 11.8V. The actual output voltage is obtained by multiplying it with the scaling factor which is set to 2.So the output voltage of the DC DC flyback converter is 23.6V.

VIII. CONCLUSION

Real-time simulation of DC-DC flyback converter is done with the help of FSS. Real-time simulation allows analysis of a physical system in real time . The real-time simulation result obtained in DSO is compared with the MATLAB/SIMULINK simulation result. The CCM mode of operation is used for simulation with constant duty cycle. The settling time can be reduced by proper controller design.

REFERENCES

[1] Daniel W.Hart, "DC Power Supplies", *Power Electronics*, McGraw-Hill, 2011, ch.7, sec.3, pp.267-277.

[2] Hafiz Kashif Iqbal, and Dr. Ghulam Abbas, "Design and Analysis of SMC for Second Order DC-DC Flyback Converter",in *Int. Multi-Topic Conference (INMIC), 2014.*

[3] Shelma George, Renji V. Chacko, "Average Modelling of Power Electronic PWM Converters for Real- Time Simulation of EV/HEV Systems", in *International Conference on Advanced Trends in Engineering and Technology-2014.*

[4] P. M. Menghal, Dr. A. Jaya laxmi, "Real time simulation: recent progress & perspective", in Conf. Rec. *Int. Journal Of Electrical Engineering And Electrical Systems (IJEEES) , 2010 , Volume 03, Issue No 01, pp [45-59].*