Real Time Simulation Of Full-Bridge DC-DC Converter using Miniature Full Spectrum Simulator

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***Abstract*— Advances in power electronics and energy storage devices have accelerated penetration of the distributed generation using renewable energy sources into electric power generation systems. Most of this generation unit has DC output and in order to produce higher AC voltage from the DC output voltage, they must have a DC-DC boost converter and a DC-AC inverter. Among the available DC-DC Boost converter topologies, Full-Bridge converter is the most attractive one for high power generation. Here, Real-time simulation of Full-Bridge DC-DC converter is done using Miniature Full Spectrum Simulator (FSS-Mini), a simulation system to address the entire spectrum of simulation namely, Offline simulation, Real-time simulation and Hardware in Loop (HiL) simulation. The simulation results (variables) will be available in real-time and can be interfaced with a controller in the Hardware in Loop (HiL). Power electronic converters are operated at high frequencies which is not practically achievable with current real-time simulation platform technology. Therefore, average modelling of converter is done and model is validated using MATLAB/ SIMULINK. Real-time library of Full-Bridge DC-DC converter is created in FSS-Mini and real-time simulation is done. This library can be effectively used in controller development and testing for the particular converter.**

Keywords—Real-Time simulation; FSS-Mini; HiL

I. INTRODUCTION

Today, electric drives, power electronic systems and their controls are getting more and more complex, and their use is widely increasing in all sectors. Advances in Microprocessors, Microcomputers, and Microcontrollers such as DSP, FPGA, dSPACE etc. and Power Semiconductor devices have made tremendous impact on electric motor drives. Due to advancement of the software tools like MATLAB/SIMULINK with its Real Time Workshop (RTW) real time simulators are used extensively in many engineering fields, such as industry, education and research institutions.

II. 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. 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.

A. Advantages of Real-Time Simulation

Design issues can be discovered earlier in the process, enabling required tradeoffs to be determined and applied, thereby reducing development costs. Testing costs can be reduced since HIL test setups often cost less than physical setups and the real-time simulator employed can be typically used for multiple applications and projects. Also, risky or expensive tests using physical test benches can be effectively replaced.

III. MINIATURE FULL SPECTRUM SIMULATOR

Full Spectrum Simulator (FSS) is an indigenously developed system that provides both off-line and real-time simulation capabilities at an affordable cost, easily configurable for custom applications.The system has Hardware in Loop (HIL) feature for Power Electronics and Power Systems. In HIL simulation, the simulated system parameters are obtained in real time, and evaluation of control hardware and software development can be realized without the need for actual physical system. The real-time simulation is carried out on a dedicated high speed digital parallel processing hardware. A PC will be used to configure the simulation application, circuit entry, compilation etc.

IV. FULL-BRIDGE DC-DC CONVERTER

DC-DC converters can be used to boost and regulate low output voltage of any DC source like some new distributed generation units to high voltage and compensate for its slow response during the transient. The main task of these converters is to maintain the output voltage at constant and predefined level. To boost low voltage DC to high voltage DC and to provide isolation, a forward boost converter, a push-pull boost converter or an isolated full-bridge DC to DC power converter can be selected. Among these power converters, Full-Bridge converters are the most attractive topology for high power generation.

A fullbridge DC-DC Converter with centre tapped configuration is shown in Fig.a. The switching topology used for the full-bridge converter is the bipolar voltage switching, where the switches are switched in pairs. Switches Sw_1 and Sw_2 are considered as one switch pair and switches Sw_3 and Sw_4 are considered as the other switch pair.

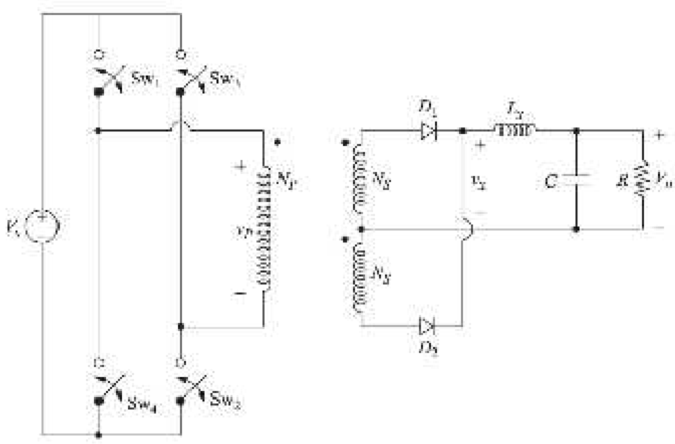

Fig. a. Full-bridge DC-DC Converter

Assuming that the transformer is ideal, the full-bridge converter of Fig.a has switch pairs(Sw_1 , Sw_2) and (Sw_3 , Sw_4). Switchinf sequence is shown in Fig.b. When Sw_1 and Sw_2 are closed, the voltage across the transformer primary is V_s. When Sw_3 and Sw_4 are closed, the transformer primary voltage is $-V_s$. For an ideal transformer, having all switches open will make v_p=0. With a proper switching sequence, the voltage v_p across the transformer primary is the alternating pulse waveform. Diodes D_1 and D_2 on the transformer secondary rectify this waveform to produce the voltage v_x as shown in Fig.c. Analysis proceeds by analyzing the circuit with either switch pair closed and then with both switch pairs open.

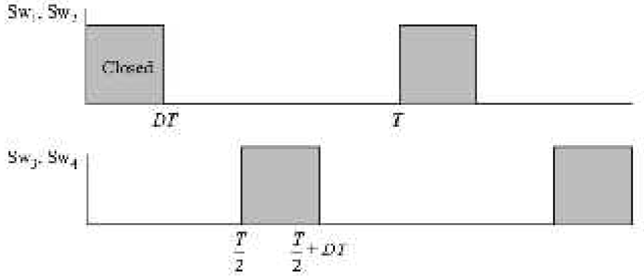

Fig.b. Switching Sequence

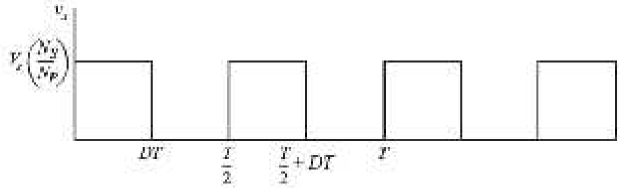

Fig.c. Rectified voltage

A. Average Modelling

The power electronic converters are normally operated at frequencies of the order of 10KHz. Simulation of these systems require a sampling of the order of 1µs. This is not practically achievable with current real-time simulation platform technologies. Moreover, for applications like controller development, we require only the average behaviour of switchingcircuits. Hence to simulate, average modelling of full-bridge DC-DC converter is crucial.

Mode1: Switches Sw_1, Sw_2 are ON

$$K \quad : n_{s} = R_T \; I_L + L\frac{d_{L}}{d} + V_o$$

$$K \quad : I_L = C\frac{d_{o}}{d} + \frac{V_o}{R}$$

where $R_{TH} = 2n^2 r_T + r_D$
$n = N_S/N_P$
r_T = on state resistance of switch.
r_D = on state resistance of diode.

$$\begin{bmatrix} \frac{d_{1}}{d} \\ \frac{d_{2}}{d} \end{bmatrix} = \begin{bmatrix} \frac{-R_T}{L} & \frac{-1}{L} \\ \frac{1}{C} & \frac{-1}{R} \end{bmatrix} \begin{bmatrix} X_1 \\ X_2 \end{bmatrix} + \begin{bmatrix} \frac{n}{L} \\ 0 \end{bmatrix} V_s$$

X_1= inductor current
X_2 = capacitor voltage

$$V_0 = \begin{bmatrix} 0 & 1 \end{bmatrix} \begin{bmatrix} X_1 \\ X_2 \end{bmatrix}$$

$$A_1 = \begin{bmatrix} \frac{-R_T}{L} & \frac{-1}{L} \\ \frac{1}{C} & \frac{-1}{R} \end{bmatrix} B_1 = \begin{bmatrix} \frac{n}{L} \\ 0 \end{bmatrix} C_1 = \begin{bmatrix} 0 & 1 \end{bmatrix}$$

Mode2 : All Switches are OFF

$$K \quad : 0 = r_L \frac{I_L}{2} + L \frac{d_{\ L}}{d} + V_o$$

$$K \quad : I_L = C \frac{d_{\ o}}{d} + \frac{V_o}{R}$$

$$A_2 = \begin{bmatrix} \frac{-r_D}{2L} & \frac{-1}{L} \\ \frac{1}{C} & \frac{-1}{R} \end{bmatrix} B_2 = \begin{bmatrix} 0 \\ 0 \end{bmatrix} C_2 = \begin{bmatrix} 0 & 1 \end{bmatrix}$$

Averaging:

Here, 1st and 2nd half cycles are identical. Hence averaged model of this converter in time T/2 is obtained as:

$$A = A_1 2D + A_2(1 - 2D)$$

$$A = \begin{bmatrix} \frac{-R_T \ \ 2D + \frac{r_D}{2}(1-2D)}{L} & \frac{-1}{L} \\ \frac{1}{C} & \frac{-1}{R} \end{bmatrix}$$

$$B = B_1 2D + B_2(1 - 2D) = \begin{bmatrix} \frac{2D}{L} \\ 0 \end{bmatrix}$$

$$C = C_1 + C_2(1 - 2D) = \begin{bmatrix} 0 & 1 \end{bmatrix}$$

V. SIMULATION RESULTS

A 2KW full-bridge DC-DC converter is designed and the output filter of the converter is so designed that there is 20% ripple in inductor current and 1% ripple in output voltage. Table 1. shows the system parameters for which simulation is done. Fig.d. shows the block diagram representation of the converter. Offline simulation results using FSS-Mini are shown in Fig.e.(ouput voltage) and Fig.f.(inductor current). Real-time simulation results are shown in Fig.g.(output voltage) and Fig.h.(inductor current). Input voltage is assumed as 50V and therefore duty ratio is 0.42.

TABLE I. SYSTEM PARAMETERS

Input Voltage (V)	45-50
Output Voltage (V)	420
Output Power (KW)	2
Switching Frequency (Hz)	2000
Transformer Voltages	50:500
Inductance (mH)	17.6
Capacitance (μF)	9
Load resistance (Ω)	90

Fig.d. Block diagram representation of full-bridge DC-DC converters

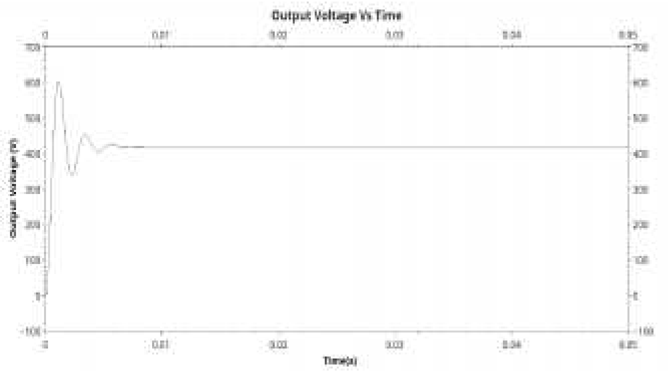

Fig.e. Offline simulation result- Output voltage vs Time

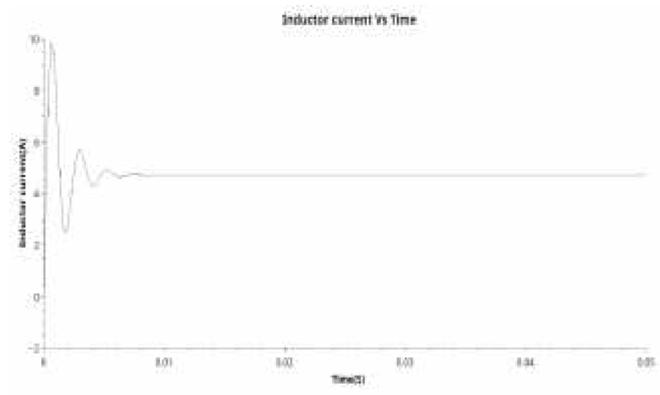

Fig.f. Offline simulation result- Inductor current vs Time

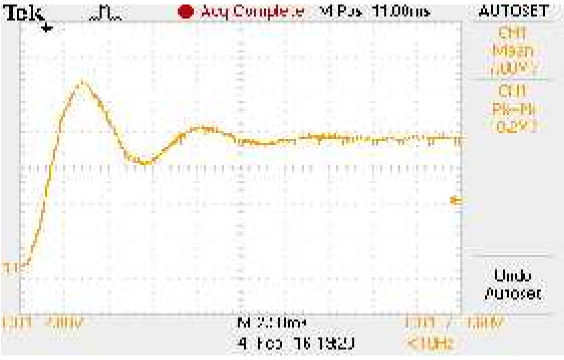

Fig.g. Real-time simulation result-Output voltage vs Time, scale- 1:60

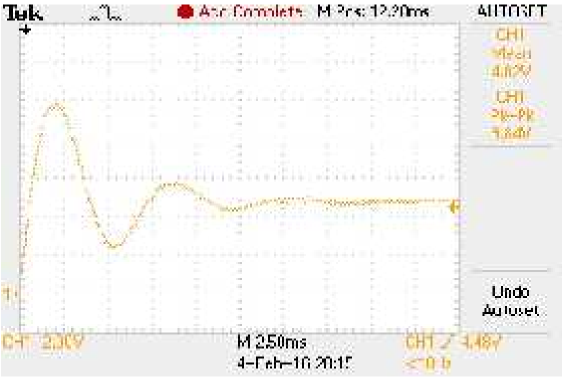

Fig.h. Real-Time simulation result- Inductor current vs Time, scale- 1:1

VI. CONCLUSION

A Fullbridge DC-DC Converter was designed. Average modelling of the converter was done. Model was then validated using MATLAB/SIMULINK. Offline and Real-time simulation of Fullbridge DC DC converter was done using FSS Mini. For that offline and real-time library element of Fullbridge DC DC converter was created and thus FSS-Mini library was enhanced. The FSS mini is developed mainly for training and research on real- time simulation of power electronic converters in educational institutions. Mini-FSS can be employed as a useful tool in testing and simulation of various basic converter circuits using their averaged models. The Command line interfacing and assembly level coding in FSS are not very popular choices. But once acquainted with procedures, it becomes a lot easier. It may not compete with the sophisticated real-time simulators available in the market now. But it is set up nicely for developing a basic understanding on the concepts of real-time simulations. Further development in SEQUEL, the graphical offline simulation environment for FSS will make it a lot easier to model, simulate in both offline and real-time and analyse the results.

REFERENCES

[1] Ned mohan, ”Switching DC Power Supplies” ,Power Electronics, Wiley and sons,2014, ch.10, sec.4, pp.304-322.

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

[3] Ali Asghar Ghadimi, Hassan Rastegar, Ali Keyhani, “Development of Average Model for Control of a Full Bridge PWM DC-DC Converter“in Journal of Iranian Association of Electrical and Electronics Engineers, Vol. 2, No. 1, pp: 10-23, 2005.

[4] 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.

[5] FSS Application Manual