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DSP Based High Power DC-DC Converter

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Abstract— *The aim of this paper is to present a review of recently used Digital controllers to design and implementation of 50 kW Switch Mode Power Supply (SMPS). For the implementation TMS320F28035 Digital Signal Processor (DSP) is used. The SMPS is based on LCC type series-parallel resonant converter. The SMPS is used as a DC power source for 3.5 kW CW CO_2 laser. The laser requires DC source variable from 500 V to 2 kV with maximum current rating of 25 Amp. The DC source is used in CW CO_2 laser to establish an electric discharge in the gain medium.*

The analog implementation of power controller comes with inherent disadvantage of aging, lack of flexibility etc. those are successfully overcomes by using digital based implementation. Also the choices of digital implementation platform being DSP give it a higher edge over a microcontroller.

The DSP based controller is designed using the same functional blocks as used for its analog counterpart i.e. Analog to Digital Converter (ADC), Control Law (CL) and Pulse Width Modulator (PWM). The control law is based on Proportional Integral Derivative (PID) control. The complete software for DSP controller is developed in C++ language using the Texas Instruments Code Composed Studio software. The series parallel resonant converter requires a variable frequency gate signal to vary the output DC voltage within specified range. These gate signals are generated by using DSP based controller. The DC output of SMPS has been maintained within ± 3% of set value by PID control loop algorithm implemented in DSP.

The power circuit is designed and simulated in MATLAB. The power circuit consists of SMPS in full bridge topology with LCC as resonant elements and close loop digital controller. The DSP based digital controller has been developed and tested on 50kW SMPS.

I. INTRODUCTION

Digital control of Switch Mode Power Supplies (SMPS) has obtained great research attention due to their well known advantages, such as programmability, advanced control algorithms, reduced component count, low sensitivity to external factors or aging, ease of design and prototyping, etc. Furthermore, it is possible to implement control schemes that are considered impractical for analog realizations. For examples, the ability to precisely match phase-shifted duty ratios has been applied to develop a simple, robust control for voltage-regulator modules (VRMs). Under the strict restraint of performance/cost, there are some issues to be considered about the dedicated digital controller in practical implementation, such as resolution, speed and power consumption, the algorithm complexity, computation speed and dynamic performance.

Compared with linear power supplies, SMPS provide high efficiency, compact and light weight. SMPS find use in a wide variety of applications, ranging from a fraction of watt in on-chip power management to hundreds of kilowatts in power systems. All of these applications require efficient and cost-effective static and dynamic power regulation over a wide range of operating conditions. An analog or digital controller closes the feedback loop around the switching converter and actively controls the on/off states of the power-semiconductor devices to achieve input or output regulation.

Up to now, the demands for digital processor have been increased due to its low cost, high speed operation, and flexibility. This project describes DSP based controller of 50kW SMPS, by using Texas Instrument's 32-bit, 60MHz Digital Signal Processor TMS320F28035.

The main goal of this project is controlling the DC output voltage of the SMPS by using DSP (TMS 320F28035) based controller. It has to generate variable frequency gate signals to the semiconductor devices (IGBT) used in full bridge configuration of SMPS. It also has to regulate the output DC voltage within ± 3% of set value in control loop.

The block diagram shown in Fig.1 gives major parts of the SMPS with DSP based controller.

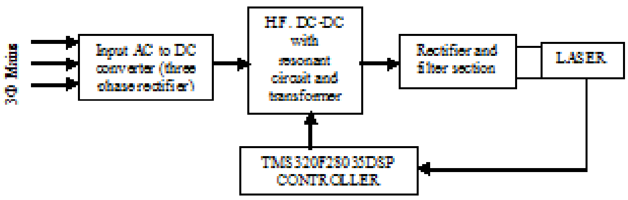

Fig.1: Block Diagram of SMPS

The DC-DC converter is based on LCC type series-parallel resonant converter. The schematic diagram of DC-DC converter is shown in Fig.2. It mainly consists of full bridge inverter operated from DC input bus, where Insulated Gate Bipolar Transistors (IGBT) is used as main switching devices. The Submicron make SKM600GA125D IGBT is used in the full bridge inverter. The resonant tank having Ls, Cs & Cp are acting as a series-parallel resonating circuit, followed by a high frequency transformer.

The high frequency, high voltage transformer is fabricated by using ferrite cores. To minimize the leakage inductance refer to primary, an primary has been wounded in parallel on two limbs of cores, where secondary has wounded on two separate limbs in view of high voltage insulation. The transformer turn ratio from primary to secondary is 1:1, having primary 18 turns. The primary as well as secondary windings are operated at 2kV, 25A current ratting due to 1:1 turn ratio. The secondary side of transformer is connected to high voltage, high frequency diode rectifier with second order (LC) filter. The gate signal generated by DSP based controller is optically isolated by using optical fiber link and given to the IGBT gate driver circuit.

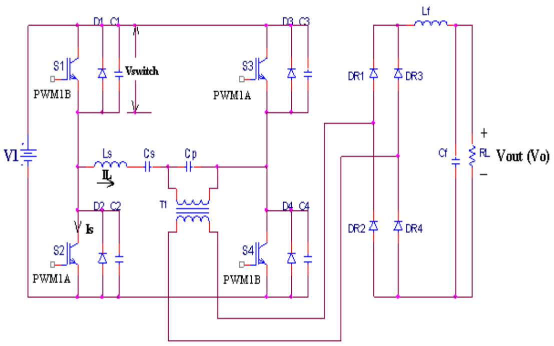

Fig.2: Schematic Diagram of LCC type Converter

II. Simulation Designing

Simulink is the mathematics software that uses the transfer function to build the behavior model of the circuit. Through simulation results of Simulink model, we can realize the feasibility of the proposed DC/DC converter quickly. According to fig. 3, the designing of the controller is being done in the Matlab using Simulink. Simulation Model of the Power Circuit is shown in Fig.3. Table below shows the rating and values of components required in s/w simulation.

S.No.	components	Rating
1.	DC input voltage	560 V
2.	Input current	90 A
4.	Four- IGBT Switches:	
	Snubber resistance [Rs]	100 ohms
	Snubber capacitance [Cs]	1 nF
5.	Transformer	1:1
6.	Input Frequency(Varaible)	22-26 KHz
7.	P.I. Controller :	
	Proportional Gain [Kp]	1.0
	Integral Gain [Ki]	0.125
8.	Output Load	80 ohms
9.	Output current	25A
10.	Output DC Voltage [Vdc]	2000 V
11.	Resonant Tank circuit	
	Series inductor[Ls]	200µH
	Series capacitor[Cs]	1.6µF
	Parallel capacitor[	0.4 µF
12.	Filter Section	
	Inductor	980 µF
	Capacitor	250 nF
13.	Output Power	50 kW

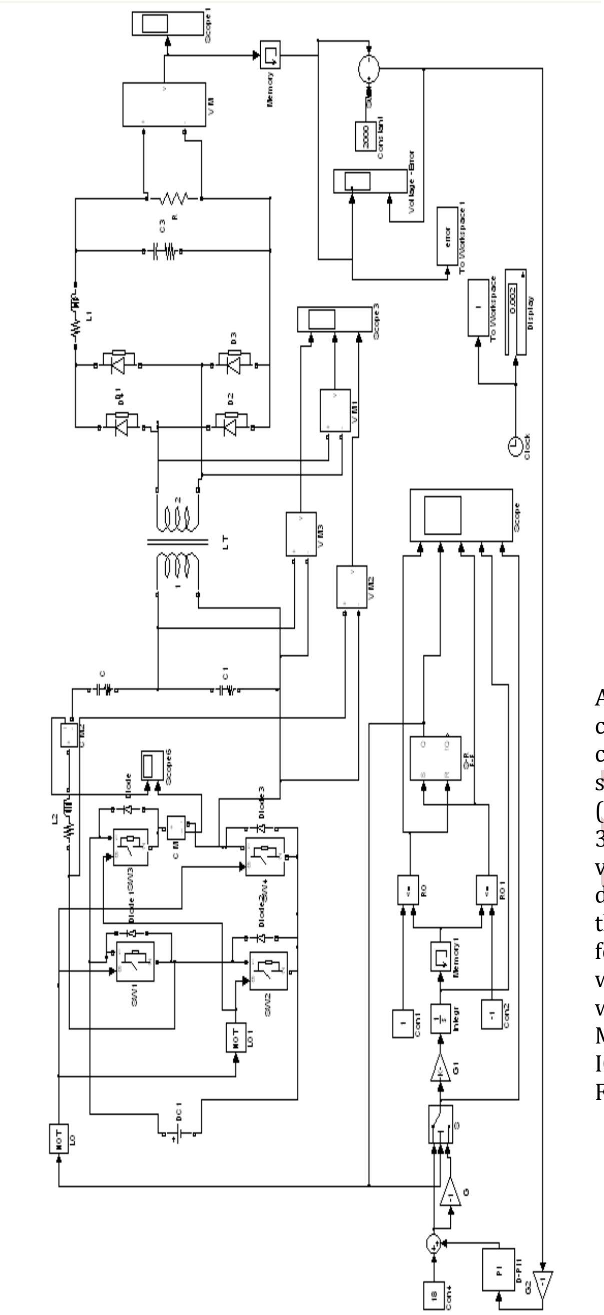

Fig.3: Matlab Power Circuit Model Diagram

III. SIMULATION RESULT

Resonant DC-DC converter output result of simulation shows Output DC Voltage at 80 ohm Resistive load is 2000V.

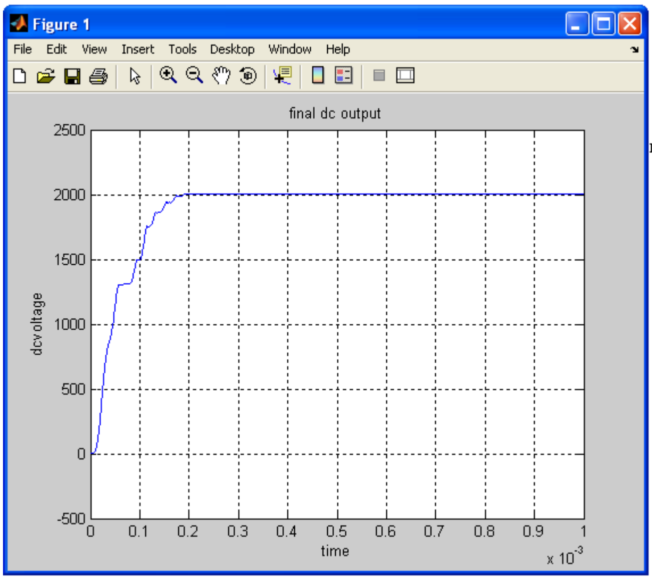

Fig.4: Simulated O/P DC Voltage 80 ohm resistive load.

IV. DIGITAL DESIGNING AND IMPLEMANTATION

A driver is an electrical circuit or other electronic component used to control another circuit or other component. The close loop controller block diagram is shown in Fig. 5. In this controller the DSP (TMS320F28035) controller generates EPWM signal at 3.3 volt logic level, this signal level was converter to 12 volt level by MIC4424 (MOSFET Driver) suitable for driving the fiber optical transmitter, at the other end this signal is used to drive the IGBT gate driver suitable for turning on/off the IGBT. The driver circuit output waveforms are shown in Fig.(a). This figure shows waveforms of EPWM (Enhanced Pulse Width Modulation), which is generated by DSP controller. The IGBT gate drive waveforms are monitored and shown in Fig.(b).

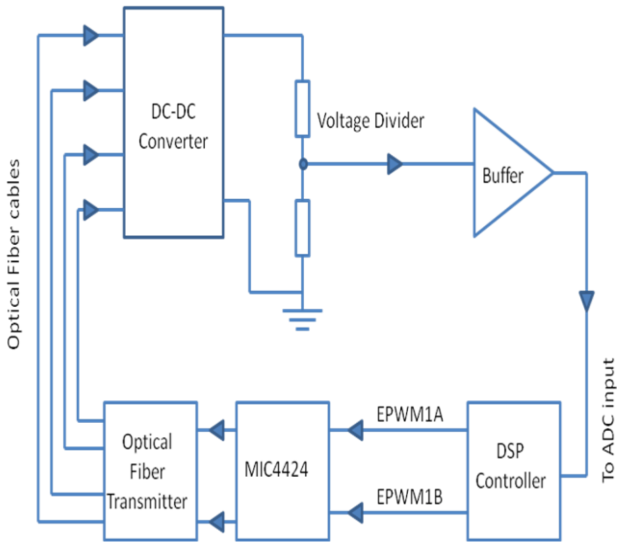

Fig.5: Close loop controller with driver circuit

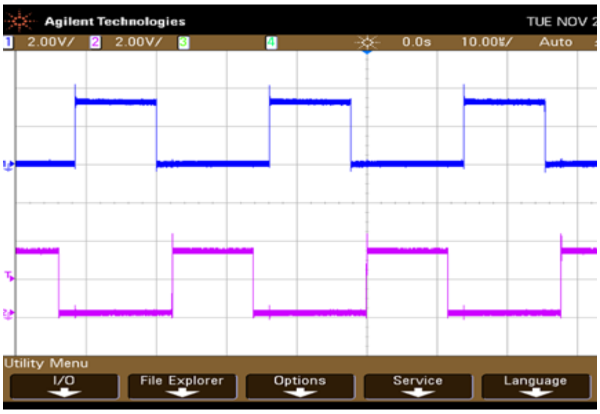

Fig.(a): EPWM Waveforms

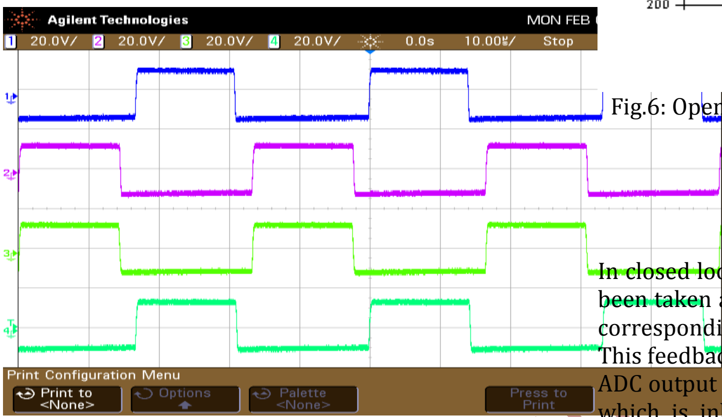

Fig.(b): IGBTs Gate Signals

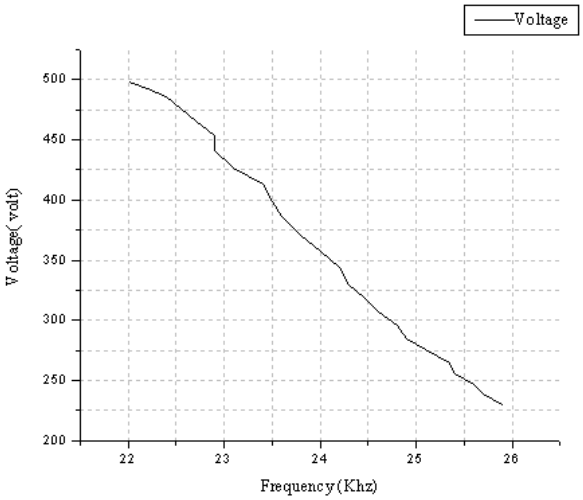

Fig.6: Open Loop Response Curve at the reduced input voltage level.

Open loop testing of the DSP controller has done at reduced voltage level, on table top 50kW SMPS. The frequency v/s open loop output voltage response is recorded and shown in Fig.6. In this experiment input DC bus voltage is fixed and by varying the frequency from 22 kHz to 26 kHz the open loop output voltage is plotted. At lower frequency (22 kHz) the open loop output voltage is on its maximum level (500volt), where at higher frequency (26 kHz) the output voltage falls down to its minimum level (225 volt). Throughout the frequency range of operation all the switching devices are operated under soft switching states i.e. Zero Voltage Switching (ZVS). The data monitored during open loop test is useful for DSP operation in close loop.

V. CLOSED LOOP TEST

In closed loop setup, firstly the SMPS output voltage has been taken as a feedback signal. It gives 0 to 2.5V signal corresponding to 0 to 2kV open loop output voltage. This feedback signal is given to ADC input of DSP. Where ADC output is used as an input of PID controller routine, which is inbuilt DSP. PID reads this ADC output and calculates the error between feedbacks and set value, correspondingly it changes the EPWM frequency. The PID works such that, to increase the SMPS output voltage, it reduces the EPWM frequency and vice-versa in a range of 22 kHz to 26 kHz. The developed controller has been tested in close loop with 50 kW SMPS and results are recorded as shown in Fig.7. These waveforms are captured and represent SMPS output voltage, one of the IGBT's collector to emitter voltage (F_t) and IGBT collector current. Fig.8 Shows the whole setup.

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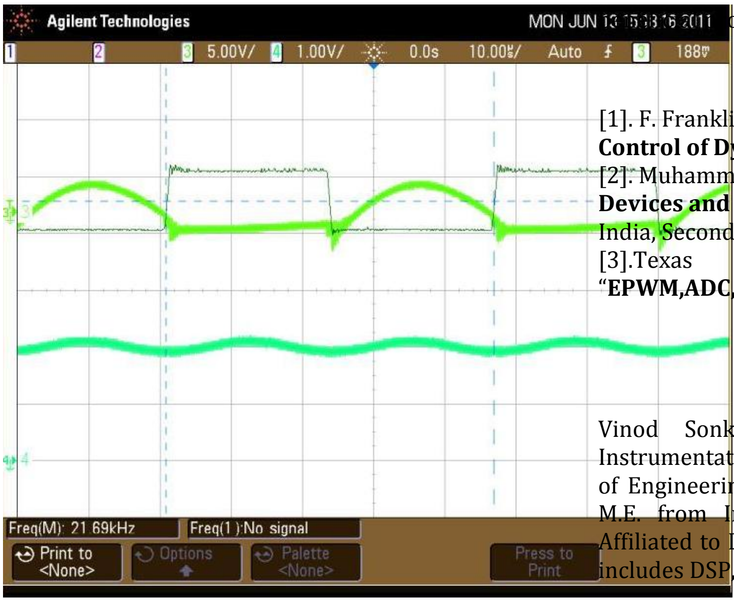

Fig.7: DC-DC Converter Closed Loop Waveforms

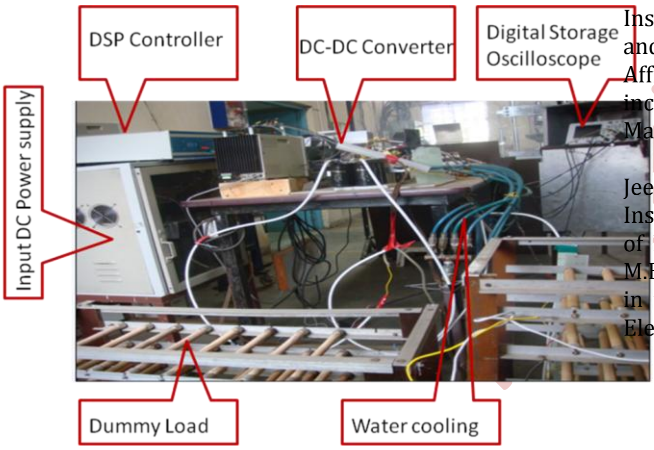

Fig.8: DC-DC Converter Setup

VI. CONCLUSION

The DSP based controller has been designed, simulated, developed and tested with table top 50kW SMPS. It is observed that the DSP based controller has performed better than analog control. The better performance is achieved by implementing high resolution EPWM, faster 12bit ADC with synchronized sampling and PID algorithm using IQmath. The experimental result shows better reliable controller with an output regulation of ±2% and faster correction within 1ms for all load conditions by using DSP based controller. Initially the model and simulation is carried out in Matlab - Simulink simulation platform. These simulated results are verified with the experimental setup are presented in this report.

7. AC

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