CONTROLLER DESIGN FOR REGULATED HIGH VOLTAGE POWER SUPPLY

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Abstract- The paper describes design and simulation of an embedded Pulse Step Modulation (PSM) scheme for Regulated High Voltage Power Supply (RHVPS) is proposed. The design involves development of a mathematical model for the proposed controller in order to arrive at the overall system architecture and evaluate the control parameters for the same. The evaluation of a parametric Integral controller has been done. The feedback control is evaluated for the purpose.

The system design is verified through circuit simulations followed by validation through implementation on a prototyping board by also developing the necessary drive interface.

Index Terms—RHVPS, PSM

I. INTRODUCTION:

Regulated High Voltage Power Supplies are major components of any high power heating and current drive system. The system uses the pulse step modulation technique for control of the series switches of each switched power module fed from multi-secondary transformer[1]. Pulse step modulation has been invented in late nineties by Swanson for fast pulses to improve the efficiency of the system [4]. The typical application areas of such RHVPS include the accelerator driven systems comprising high power supplies of the order of 100 kV/25 A for the regulation of fields in reactor control.

The proposed project deals with design and simulation of an embedded PSM scheme for regulated high voltage power supply. The design involves the development of a mathematical model for the proposed controller in order to arrive at the overall system architecture and evaluate the control parameters for the same. The evaluation of a parametric Integral feedback control scheme is proposed.

The system and block level specifications are derived from the system model simulations and system architecture proposed for implementation. Simulation for the proposed controller model has been done using MATLAB Simulink®.

The hardware implementation will be implemented considering series connected switching stacks by developing the necessary drive interface.

II. A TYPICAL RHVPS

The basic RHVPS system architecture is shown in Figure 1. The system essentially comprises a series connection of N switched independent voltage sources \(V_a\) to the power supply output by series switches \(S_i\) to \(S_N\) constituting the switched power supply modules (SPM). The proposed embedded PSM controller controls the switches. The required switch ON/OFF times in of the order of microseconds. The operation of the basic PSM technique, involves switching of the required number of isolated identical copies of SPMs. Each SPM in the series stack is switched on with the required duty cycle. The generation of the resulting output voltage \(V_{\text{load}}\) for the five SPMs connected in series is as shown in the figure below.

![Figure 1: Basic Architecture of RHVPS](image-url)

As shown in figure 1, the operation of a basic PSM technique involves switching of the required number of switched power modules, SPMs that are identical and isolated from each other. Each SPM in the chain of stack is switched on with the required duty cycle.

When the series switch \(S_i\) is turned on then the corresponding freewheeling diode will be reverse biased.
and the remaining diodes will be forward biased. Then the input voltage $V_{a1}$ appears across the load. Then the series switch $S_2$ is turned on, now both $S_1$ and $S_2$ will be in on position, then the voltage $V_{a1}$ and $V_{a2}$ appears across the load. In the same pattern all the series switches are turned on and off in a cyclic order.

These five SPMs being switched in a manner shown by their output voltage pattern $V_{a1}$ to $V_{a5}$. The switching of each SPM is controlled in a cyclic fashion to equalize the average loading of all SPMs. This facilitates use of identical SPMs. Naturally a switching pattern shows characteristics of both PSM and PWM (pulse width modulation). The output waveform is DC with ripple voltage of $V_{a}$ (peak to peak) and ripple frequency of $N$ times SPM switching frequency ($f_{Ms}$). When these voltage sources are switched on and off with required duty cycle the resulting waveform will be in the stepped sine waveform.

### III. SYSTEM ARCHITECTURE

![Figure 2: High voltage power supply using PSM Controller](image)

Figure 2 shows number of series connected switched power modules along with PSM controller. The SPM works with the local reference voltage, which is one SPM voltage. The regulated voltage is switched to output load with series switches. SPM is designed with conventional power electronics, except for static discharge considerations. These are switched ON and OFF at a duty cycle of a maximum of 95% and at a frequency of 50 kHz. This switching is controlled by PSM controller by duty cycle control and adequate derating of the switch. In the figure 80 SPM stacks are connected in series out of 80 stacks required number switches can be switched in a cyclic order. Also, RHVPS operates at rated load with high reliability for long time.

Bypassing of the SPM during operational period does not result in any change at power supply output because of the instantaneous modification carried out in PSM and PWM switching pattern. SPM draws its control power from an input supply. It has an independent safety system for overload, input under voltage, output short circuit, switch failure and usual protections for the semiconductors.

The PSM controller is a control system for RHVPS and performs two basic functions,

- Generate PSM control signals for each of the SPM and
- Provide control parameters.

The RHVPS output is connected to the load. Depending on the parameters of the load, and the system performance requirements, the output needs to be filtered. A network for filtering is a low-pass filtering circuit for specific transient/dynamic performance operating at the output voltage of the RHVPS. The feedback control system is used with integral controller in the feedback path.

### IV. SOFTWARE IMPLEMENTATION

In the project, we have used MATLAB SIMULINK software for simulation of PSM controller

Implementation of open and closed loop PSM controller for regulated power supply in MATLAB SIMULINK

To verify the proposed schemes of PSM techniques, a simulation model for four switched power modules are implemented. The simulation parameters for constant switching frequency pulse step modulation are as following, each source $V = 5V$, switching frequency 50KHz. The delay in switching each power module is 0.143 microseconds. The MATLAB SIMULINK model of open loop Pulse Step Modulation for four voltage sources and a switching frequency of 50KHz shown in Fig 3.

![Figure 3: Open Loop PSM Controller](image)

Closed loop PSM controller for four switched power modules is implemented. The simulation parameters for constant switching frequency pulse step modulation are as following, each source $V = 5V$, switching frequency 50KHz. The delay in switching each power module is 0.143 microsecond. The R-C low pass filter is used at the output to eliminate the ripple frequency of 200KHz. An Integral controller is used in the feedback path to stabilize the system. An output signal from integral controller serves as input to the controller subsystem. MATLAB SIMULINK model of open loop Pulse Step Modulation for four voltage sources is shown in Fig 4.
V. HARDWARE IMPLEMENTATION

The hardware circuit for pulse step modulation of four voltage sources is implemented based on the block diagram of the control operation shown in the fig5 below. The output from a stable multi vibrator circuit is connected to driver circuit. This is to provide triggering pulse to driver circuit. The output from driver is connected to each switching device of the switching circuit. Here the hardware built is the prototype, which is analyzed for lower voltage.

Figure 4: Closed Loop PSM Controller

VI. OBSERVATIONS

Figure 6: Experimental setup

The hardware components include opto-isolator and Gate drive circuits to drive the MOSFET switches used in series connected switched power modules, Load and Regulated Power supply for separate DC sources.

Description of the Hardware components

The hardware components include opto-isolator and Gate drive circuits to drive the MOSFET switches used in series connected switched power modules, Load and Regulated Power supply for separate DC sources.

Experimental Set up

The experimental set up of complete hardware circuit is shown in fig6. The hardware set up shows the a stable multi vibrator circuit that gives the control signals for real time control of the four series connected switched power modules. The control signals from multi-vibrator are fed to the opto-coupler input, these signals are used for triggering four MOSFET switches to get the multilevel output. The input to the switched power module is 5 V DC, which is supplied by the regulated power supply.

Figure 5: Block Diagram for four switched power modules of regulated power supply

Figure 7: output waveform of series connected four switched power modules

Figure 8: Simulation output of open loop PSM controller for four switched power modules

Figure 9: Simulation output of closed loop PSM controller for four switched power modules

The given regulated input voltage for each SPM stack is 5V, therefore the total input voltage of four SPM stacks is 20V. The stepped sine output voltage waveform is shown in Fig7. Fig8 and Fig9 shows the simulation results of open loop and closed loop PSM controller for four switched power modules.

VII. CONCLUSION

The High voltage power supply built around the PSM topology as a part of this project is suitable for continuous duty, controlled High Voltage power requirements with very fast dynamic response, and gives low ripple voltage, low stored energy and harmonic distortion, better power factor and higher efficiency. They are most efficient power supplies for the given range of power and voltage can be configured for
modulating outputs. Fast turn ON and turn OFF capabilities are features which makes it very competitive for use with high power applications.

REFERENCES


