KLYSTRON POWER SUPPLY FOR KOMAC

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Abstract

A switching mode power supply (SMPS) is a hopeful candidate for the 1MW CW klystron power supply of KOMAC (KOrea Multi-purpose Accelerator Complex). The merits of the SMPS are low stored energy, small size, high rating efficiency and possible cost saving whereas the demerits are EMI problem and system complexities. The proposed power is 2MW and it is considered that the modules, each of which has the power of 200kW, are connected in series to supply the total power. As a first step, a 200kW SMPS is studied and designed. An overview of the power supply designed so far is presented.

1 INTRODUCTION

Several different types of DC power supplies are used according to the required power of the system. Generally, above a few hundred kW power level, phase controlled rectifier (PCR) is mostly used and below a few tens kW power level, PCR, SMPS, linear mode power supply are used competitively with their own merits. But recently, it becomes possible to realize a SMPS exceeding 100kW due to advances in power electronic components. For example, a 200kW SMPS was designed for magnet power supply [1], a 400kW was operated for electron beam power supply [2]. As for klystron power supply, 1.8MW SMPS is proposed for APT klystron [2] and 570kW is studied at Daresbury laboratory [3].

The high frequency used in SMPS makes the capacitance of the output filter reduced and output stored energy small. This fact is a major merit of the SMPS for the CW klystron high voltage DC power supply compared to its counterpart PCR because it means that it will be possible to operate the power system without crowbar.

The total number of 1MW CW klystrons required for KOMAC is 31 (CCDTL : 8, SC Linac : 23)[4]. At the first stage, commercial klystrons will be used, but it is planned to develop the klystron system including power supply and energy recovery system in KOMAC project. The SMPS is a hopeful candidate for the KOMAC klystron power supply. The specification of the SMPS is represented in Table 1. The voltage ripple and stored energy refer to APT data[2].

IGBTs (Insulated Gate Bipolar Transistor) are used as high frequency switches in SMPS and the specification of the IGBT mainly limits the power rating of the module to be equal to or less than 200kW.

Parameter	Value	Comment
Power	2MW	-
Output Voltage	100kV	-
Power per module	200kW	10 module
Voltage per module	10kV	Series connection
Voltage ripple	≤ 2%	Peak to peak
Stored energy	≤ 25J	-
Efficiency	≥ 90%	-

Table 1. SMPS specification for KOMAC klystron

2 200kW SMPS

2.1 Topology selection

As mentioned above, the power rating per module is 200kW (10kV, 20A) and is limited mainly by the IGBT's power ratings. The specification of the commercially available IGBTs suitable to this power level is 1200V, 600A which is produced by International Rectifier(I.R.), Toshiba, Mitsubishi and so on.

The SMPS topology required should meet the condition for the high voltage, high power operation. The PWM converter is chosen rather than resonant converter because of the limited IGBT specification. The high frequency full-bridge inverter and transformer are required for the high voltage operation and reducing the switch stresses. Generally, the full-bridge inverter is also used as the regulator by controlling the conduction period of the switch, but at high power level, such a full-bridge operation has some problems and it is preferable to adopt another regulator. So buck converter with current-fed full-bridge DC transformer is chosen as a 200kW SMPS topology. The main component of the circuit is represented in Fig. 1.

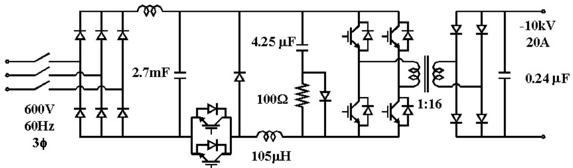

Fig. 1. 200kW SMPS

In this topology, it is desirable that the buck regulator is operated at twice the switching frequency of the inverter switches and in phase with them [5]. The switching frequency is related to the power rating of the switch and it is recommended to operate the IGBT at frequencies below 10kHz by I.R.. So it is decided that the inverter is operated at 10kHz with fixed 0.5 duty ratio and the regulator is operated at 20kHz by alternately gating two IGBTs at 10kHz. The overvoltage snubber circuit is connected across the inverter to prevent voltage spikes during the switch turn off.

2.2 Thermal analysis

The junction to case thermal resistance of the IGBT differs somewhat according to the company. In this calculation, MG600Q1US41 (Toshiba's IGBT) is selected. The maximum junction and heat sink temperature are decided to be 105°C and 60°C respectively. It is assumed that the case to heat sink thermal resistance is 0.05°C /W. The allowable power dissipation of the IGBT is 530W under the above conditions. The power loss of the IGBT consists of the conduction loss and the switching loss. The steady state large signal characteristics show that the average inverter current is 308A. From this current, the conduction loss is 370W which is 70% of the allowable power dissipation. As for switching loss, the available data is insufficient and the value is different according to specific circuit considered, but it is considered that the value is somewhat large because of the PWM operation. So snubber circuits to reduce the switching loss may be necessary.

2.3 Control

Direct duty ratio control is a candidate because it is simple and the system needs no current sharing. The block diagram of the feedback control system is shown in Fig. 2.

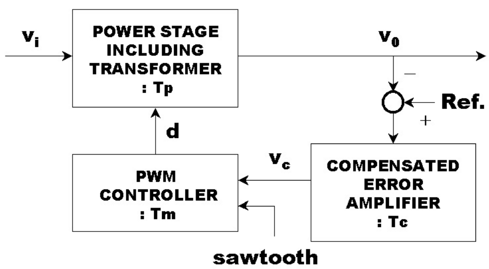

Fig. 2. Block diagram of the feedback control system

The transfer function of the power stage can be obtained from the state-space average model. In designing the compensated error amplifier, two systems are considered and compared, one is two poles with one zero system (Case1) and the other is three poles with two zeros system (Case2). The open loop and closed loop characteristics of each case are represented in Table 2. The result shows that Case2 is relatively more stable than Case1. The bode plot of the open loop transfer function for Case2 is represented in Fig. 3.

		Case1	Case2
Open loop transfer ft.	Phase margin	45°	44°
	Gain margin	6dB	24dB
Closed loop response to step ft.	Rise time(0-100%)	670μs	80μs
	Settling time (δ = 1%)	2.3ms	2ms

Table 2. Open loop and closed loop characteristics

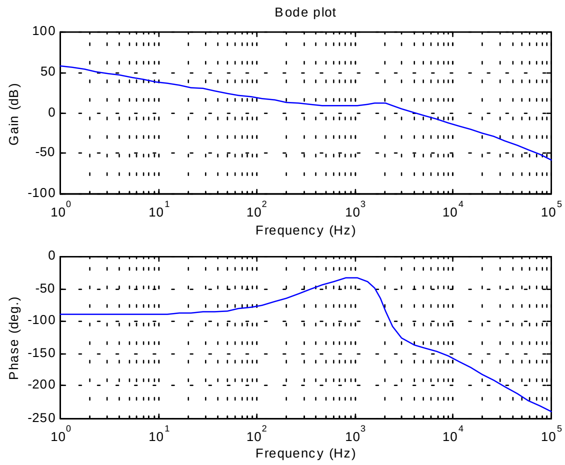

Fig. 3. Bode plot of the open loop transfer function

3 MODULE CONNECTION

In section 2, major concepts of the 200kW SMPS are determined and here module connection concept is considered from the above results. The schematic diagram is represented in Fig. 4.

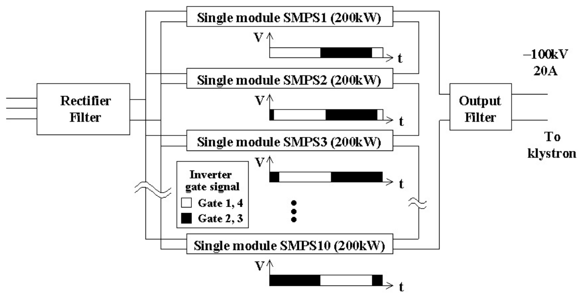

Fig. 4. Module connection concept

3.1 Input connection

Ten modules are connected in parallel from the same DC line at the input section. The input filter should be carefully designed not to produce undesirable interactions among the modules [6]. The filter properly designed tends to decouple the negative regulator impedances from the DC line, leaving only the passive input filter impedances to affect the other module. Addition to this input filter, common mode EMI filter may be necessary because of the high frequency ripple of the input filter capacitor. So the input filter represented in Fig. 1 should be modified to meet some criteria.

3.2 Output section

The modules are connected in series to supply the 100kV output voltage to the klystron. It is not determined how to design the output filter yet, but two methods are considered. One is to place the inductor at the output of each SMPS and a single output capacitor across the klystron. In this case, each of the single module SMPS acts like a current source. The other method is to place one inductor and capacitor across the output of the ten series connected modules like a single LC low pass filter. In this case, each of the single module SMPS acts like a voltage source. The important criteria that should be satisfied in both cases are the output stored energy and output voltage ripple specification represented in Table 1.

3.3 Multi-phase operation

It is common to increase the output voltage ripple frequency in series connected SMPS by multi-phase operation. Each inverter is shifted into 36° of phase difference to each other. To achieve this somewhat complex phase shifted gate signal, master and slave inverter concept using digital control is accepted [3].

4 CONCLUSION

The SMPS has some merits as a klystron power supply for KOMAC. As a first step, the topology selection and some preliminary analysis of the 200kW SMPS have been carried out. Now, multiple module connection concept is under consideration and being studied.

5 REFERENCES

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