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Simulation of Klystron-Modulator using Pspice for Applying New Klystrons in KOMAC

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1. Introduction

For operating a 100 MeV proton accelerator in KOMAC (Korea Multi-purpose Accelerator Complex), the modulator has been used as a pulse power supply to drive two or three klystrons. In KOMAC, four modulators drive nine klystrons, which supply RF power to the DTL tank. The specifications of a modulator that drives two klystrons are shown in Table I.

Table I: Specifications [1]

Peak Power	5.8 MW
Pulse width	1.5 ms
Max. Repetition rate	60 Hz
Duty	9%
Input voltage to SCR	3.3 kV_{ac}
Max. output voltage from SCR	2.2 kV_{dc}
Flat-top output voltage	105 kV
Flat-top output current	50 A

Because klystron has a lifetime, the engineers have to change the klystron with new one before the klystron meets the end of lifetime. From September 2018 to February 2019(maintenance period), the engineers in KOMAC worked to change the two klystrons which nearly meet the end of lifetime.

Before this maintenance period, KOMAC used 9 klystrons manufactured by THALES. After we changed existing klystrons with new klystrons in this maintenance period, we can also operate two klystrons manufactured by Toshiba.

For applying new klystrons manufactured by Toshiba, we should consider the suitability of the modulator output characteristics when installing new klystrons to the existing modulator.

In this paper, the analysis of the modulator that drives new klystrons was implemented using Pspice tool. The klystrons were modeled as a voltage controlled current source (VCCS).

2. Simulation modeling

2.1 Klystron Modeling

The klystron is the non-liner equipment that it is not modeled as a resistor in Pspice tool. The V/I characteristics of the klystron is shown in equation 1.

$$I_b = k \cdot E^{(3/2)} \quad (1)$$

Where I_b is beam current in amps, E is beam potential in volts. The constant k is a function of the geometry of the cathode-anode structure, and is termed perveance [2].

For modeling this non-linear microwave tube in Pspice, the ABM(Analog Behavioral Modeling) library especially PWR, G parts were used as shown in Fig. 1. The PWR part calculates the exponent term and the G part conducts the multiplying the perveance term. In Fig. 1, the resistors (R7~R10) were used to give the anode voltage divided from the beam voltage.

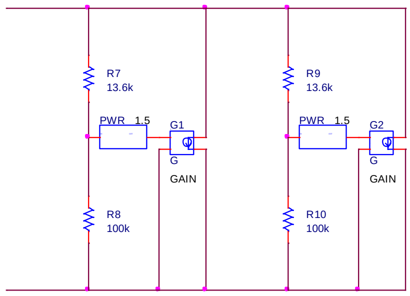

Fig. 1. Non-linear model of two klystrons in Pspice.

2.2 Modulator Modeling

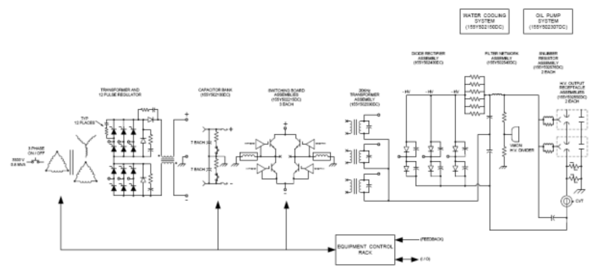

Fig. 2. Block diagram of modulator.

In Fig. 2, existing modulator block diagram was shown and also the simplified circuit diagram seen from the second side of the transformers is shown in Fig. 3 [3]. The leakage inductance of the transformers (L_a, L_b, L_c) and resonating capacitors (C_a, C_b, C_c) constitute a LC resonant circuit.

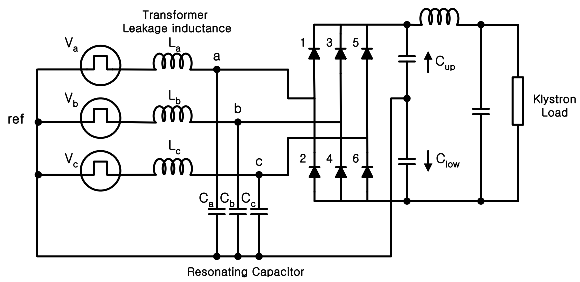

Fig. 3. Simplified circuit diagram seen from the second side of the high voltage transformer.

As shown in Fig. 2 and Fig. 3, existing modulator has a resonance topology that it is important to consider the characteristics of the modulator output when connecting the new klystrons with different perveance value. As shown in Fig. 4, Pspice schematic was modelled using Fig. 1 and Fig. 3.

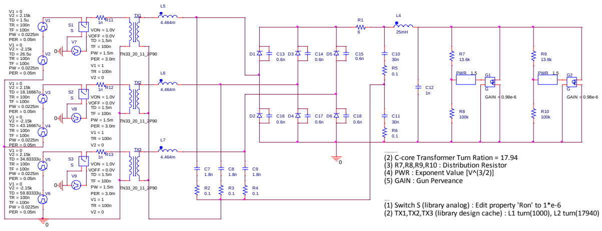

Fig. 4. Pspice schematic of Fig. 3 that was consolidated with non-linear model of Fig. 1.

3. Simulation result

3.1 Modulator output voltage

The operation data of the modulator that drives two Toshiba klystrons is shown in Table II.

Table II: Operation data of M01

M01 SCR Voltage	Output Voltage
2.15 kV	100.5 kV

The modulator output voltage waveform is shown in Fig. 5. This simulation result of modulator output voltage is 99.275 kV which value has an error of 1.2% compared with operation data.

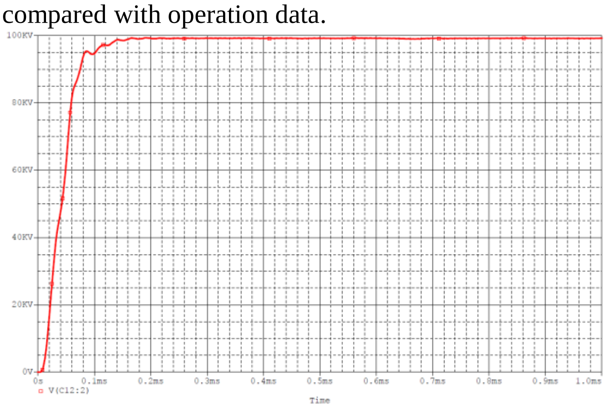

Fig. 5. Output voltage of the modulator with new klystrons.

3.2 Modulator transformer currents

From the currents waveform of the boost transformer, we can figure out the suitability of resonance characteristics in existing modulator [4]. Fig. 6 shows the real transformer currents of three phases and Fig. 7 shows the simulation result of transformer currents in the simulation model of Fig. 4. The simulation result confirms that this simulation model and VCCS model are fairly similar to existing klystron-modulator system.

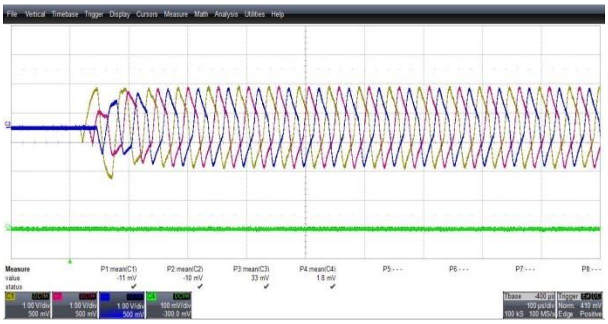

Fig. 6. Transformer currents of modulator in operation.

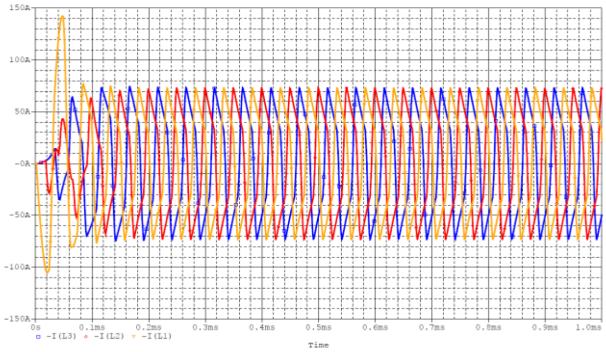

Fig. 7. Transformer currents of simulation model of Fig. 4.

4. Summary

Using Pspice which is a useful circuit analysis tool, the simulation of klystron-modulator under the operation was implemented with the allowable error. In addition, using this tool, result of the simulation confirms that the LC resonant circuit topology is still effective with Toshiba new klystrons.

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