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The Study on the Electrical Characteristics of the Pulse Generator adopted Cascading Technique

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ABSTRACT

The pulsed power systems have been widely used many other countries and their new applications have been developed by many researchers, such as E/P(Electrostatic Precipitator) to remove the industrial dust, DeNOx/DeSOx power systems, ozone generators and power sources of the laser beam, etc. In this paper, we studied the cascading technique as a new technology consisted of two pulse transformers and obtained their experimental data and results. To obtain the high pulsed voltage adopted cascading technique, we designed our compact pulse generator and tested by adjusting the value of the load resistors to obtain high pulsed voltage with steep rising time and duration time. We explained their experimental results that obtained by adopting cascading technique. Also, we compared theoretical value with measured value obtained by using the cascading method.

Keywords : Pulsed power systems, Cascading technique, Pulse transformers, Pulse generator, Load resistors

1. Introduction

Recently the pulsed power systems have been widely used to many fields, such as E/P(Electrostatic Precipitator) for removal some industrial dust, DeNOx/DeSOx power systems[1-2], ozone generator and power supply of the laser beam[3], etc. Many other countries are interested in the solution of the environmental pollution by using the practical and compact a pulse generator(P/G)[4-6]. In Ref.[4], the author constructed a pulse transformer of turn ratio about 5, and tested its insulation breakdown voltage of the pulse transformer submerged oil in USA. Ref.[5] indicated that they designed a pulse transformer and transformer in Japan. Most of the pulse generators experimented the response for a kind of pulse required pulse voltage with very steep rising time during time of the pulse duration to remove the environmental pollution[6]. In this paper, we studied the cascading technique as a new technology consisted of the two pulse transformers and obtained their experimental data and results. To obtain the high pulsed voltage adopted cascading technique of two transformers, we designed our compact pulse generator and tested by adjusting the value of the load resistors to obtain high pulsed voltage with steep rising time and duration time. We explained their experimental results that obtained by adopting cascading technique. Also, we compared theoretical value with measured value obtained by using the cascading method.

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2. Pulse Generator

2.1 Pulse Generator Circuit

Pulse generator and SCR control circuit are shown in

Figure 1. In this circuit, electrical parameters are as follows: Capacitor3(C3) 0.5 μF, L_{p1}=11μH(primary inductance of Tr1), L_{s1}=720 μH(secondary one of Tr1), L_{p2}=720 μH(primary inductance of Tr2), L_{s2} = 280mH(secondary inductance of Tr2). And coupling coefficient K is equivalent to 0.78. The charging voltage of C3 is discharged in Tr1 by triggering the gate of SCR(Silicon controlled rectifier). At this time, stored energy of Tr1 is transferred to Tr2 and load. The turn ratio α1 of Tr1 is 1:8 and α2 of Tr2 is 1:20. The range of input voltage is from minimum 60V to maximum 180V. We could obtain peak voltage of 50kV, when input voltage was 180V. Stored energy of the capacitor (*We*) and inductor (*Wh*) per unit volume are given to each equation 1 and 2. [7]

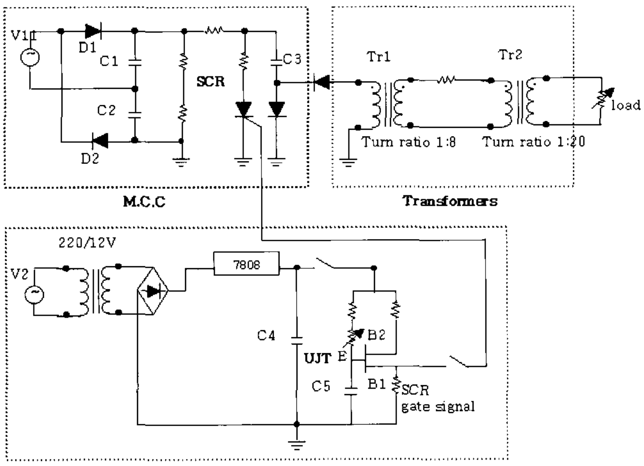


Fig. 1. Pulse generator and SCR control circuit.

$$We = \frac{1}{2}ED = \frac{1}{2}\varepsilon E^2 = \frac{1}{2}\frac{D^2}{\varepsilon}[J/m^3] \quad (1)$$

$$W_h = \frac{1}{2}BH = \frac{1}{2}\mu H^2 = \frac{1}{2}\frac{B^2}{\mu}[J/m^3] \quad (2)$$

Here, E : electrical field intensity[V/m], ε : permittivity[F/m] , D : electric flux density[C/m^2], μ : permeability[H/m], B : magnetic flux density[wb/ m^2]. And joule loss(W_L) and total stored energy of inductor(W_I) are given each equation 3 and 4. [7]

$$W_L = \int_0^T Ri^2 dt = \frac{I^2}{3}RT[J] \quad (3)$$

$$W_I = \int_0^T vidt = \int_0^I Lidi = \frac{1}{2}LI^2[J] \quad (4)$$

Here, W_L : Joule loss of inductor[J], W_I : total stored energy of inductor[J], T : charging time[s], R : electrical resistor of inductor[Ω], i : charging current of inductor[A], I : current after charging inductor[A]. Also, output voltage of pulse in load is each equation 5 and 6.[7]

$$V = \frac{V_0 R}{Z+R}\{1 - e^{-at}(\frac{a}{w}\sin wt + \cos wt)\}\ (a^2 < b) \quad (5)$$

Here, V_o : input voltage[V],

$$a = \frac{1}{2}(\frac{Z}{L} + \frac{1}{CR}),\ b = \frac{1}{LC}(\frac{Z+R}{R}),$$

$w = \sqrt{b - a^2}\ (a^2 < b)$, Z : circuit impedance[Ω],

R : load resistor[Ω] and $\zeta = a/\sqrt{b}$, $\tau_0 = 2\pi/\sqrt{b}$.

Also, $a = 2\pi\zeta/\tau_0, b = 4\pi^2/\tau_0^2$,

$$V = \frac{V_0 R}{Z+R}\{1 - e^{\frac{2\pi\zeta_t}{\tau_0}}(\frac{\zeta}{\sqrt{1-\zeta^2}}\sin(2\pi\sqrt{1-\zeta^2}\frac{t}{\tau_0}) + \cos(2\pi\sqrt{1-\zeta^2}\frac{t}{\tau_0}))\}(\zeta < 1) \quad (6)$$

By changing the load resistor(R), we can adjust overshoot in voltage waveform.

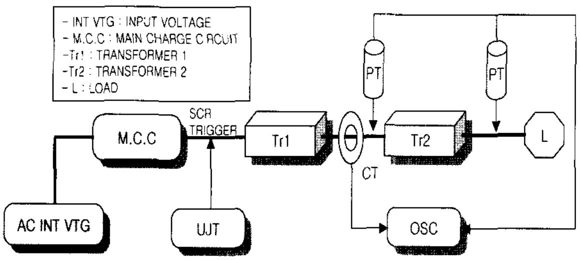
At equation (6), V has overshoot in voltage waveform likely figure 4.

$$L = \frac{\mu A_e}{l}N^2[H] \quad (7)$$

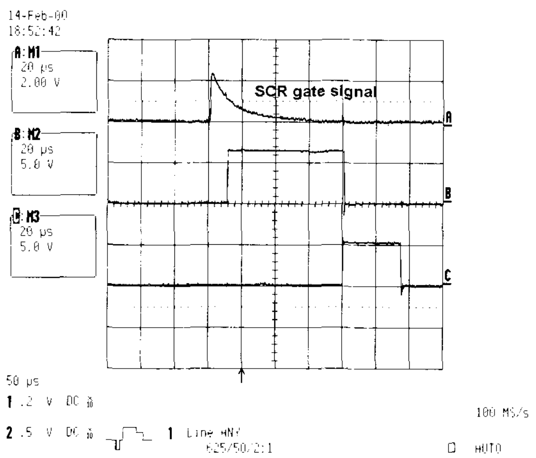
Here, Ae[m^2] is the cross area of magnetic flux. And N is turns of transformer.

2.2 Pulse generator circuit

Figure 2 shows the experimental block diagram and SCR gate signal. By using voltage divider(Model : North-Star PVM-1, 1/1000) and CT(Model : Pearson Current Monitor 4997, 1/100), we monitored the pulse waveforms by using oscilloscope (Model : LeCroy 9310AM). And we designed the control circuit parameters with UJT (Uni-Junction Transistor) to feed transmission charging energy of C3 to load in 10μs.



(a) The experimental block diagram



(b) The gate signal of SCR

Fig. 2. Block diagram of the pulse generator and SCR gate signal.

3. Experiments and Measurement

3.1 Pulse Voltage Characteristics of Load esistor 12kΩ

Each figure 3 and figure 4 show the pulse voltage waveforms of Tr1_out(non cascading voltage) and Tr2_out(cascading voltage) vs. input voltage 180V. We found that the voltage pulse with rising time of 200ns, duration of 1.5μs and peak voltage 1.1kV in Tr1_out was obtained. And peak voltage 50kV in Tr2_out was obtained. From these figures, negative voltage due to no impedance matching between stored system and load can be decreased as adjusting resistor value. They are similar to waveforms obtained by using electrodes, such as pin to pin or plate to plate electrodes instead of load resistor. For this condition, we chose resistor value and tested. We'll later study possible influence of negative voltage on the gas ionization. Figure 5 gives voltage increment ratio of Tr1_out and Tr2_out in the range of AC input voltage from 60V to 180V. We found that peak voltage is plotted in the form of linearity and yet to saturate in this figure.

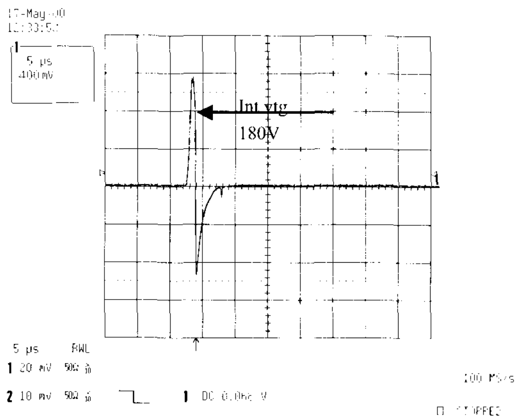


Fig. 3. Pulse voltage waveform of Tr1_out (non cascading voltage) vs. input voltage(1000V/div)

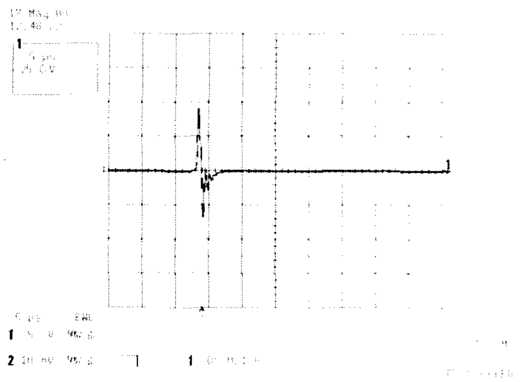


Fig. 4. Pulse voltage waveform of Tr2_out (cascading voltage) vs. input voltage(1000V/div)

Table 1 provides the T.V(theoretical value) and M/T(measured/ theoretical value) of Tr1_out & Tr2_out. The theoretical value was based on the assumption that coupling coefficient K of pulse transformer was 1. The average value of Tr2_out, cascading voltage, had about 58% of theoretical value. And this value adequately has to be considered on designing pulse transformer. We obtained the cascading pulse voltage with rising time 300ns, width 1μs, peak voltage over 50kV by using compact pulse transformer adopted cascading technique.

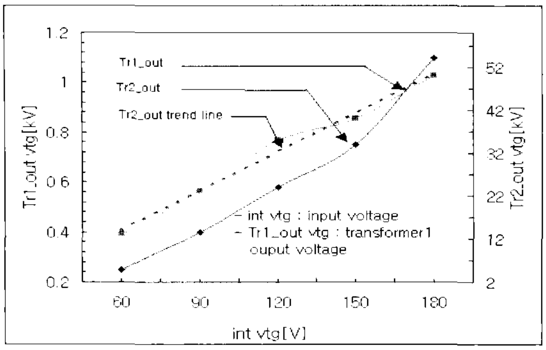


Fig. 5. Voltage increment ratio of Tr1_out and Tr2_out in the range of AC input voltage from 60V to 180V on using load resistor 12kΩ

Table 1. T.V and M/T value of Tr1_out & Tr2_out.

Int vtg[V]	Tr1_out T.V[kV]	Tr2_out T.V[kV]	Tr1_out M/T [%]	Tr2_out M/T [%]
60	1.3	26	19	50
90	2	40	20	56
120	2.7	54	21	65
150	3.4	68	22	58
180	4	80	28	63

* T.V : Theoretical Value, M/T : Measured/Theoretical Value

Table 2. M.V and cascading ratio of Tr_1 out & Tr_2 out.

Int vtg[V]	**Tr1_out M.V[kV]**	**Tr2_out M.V[kV]**	**Cascading ratio**
60	0.25	13	52
90	0.4	23	57
120	0.58	35	60
150	0.75	40	53
180	1.1	50	46

* M.V : Measured value
* cascading ratio= Tr2_out M.V/ Tr1_out M.V

Table 2 provides that M.V(measured value) and cascading ratio of Tr1_out & Tr2_out. Even though the same turn ratio α, it's different in Tr2_out M.V according to the primary and secondary inductance each of Tr1, Tr2. The more inductance had the secondary value of Tr1 than the primary one of Tr2 under same turn ratio α, the more the peak voltage decreased compared with same inductance. Because of regarding the secondary turns of Tr1 and primary turns of Tr2 as a kind of transformer, peak voltage possibly was decreased.

3.2 Pulse Voltage Characteristics of Load Resistor 24kΩ

Figure 6 indicates voltage increment ratio of Tr1_out and Tr2_out in the range of AC input voltage from 60V to 180V. Likely figure 5, we find that peak voltage is plotted in the form of linearity and yet to saturate in this figure. This output characteristics is similar to load resistor 12kΩ.

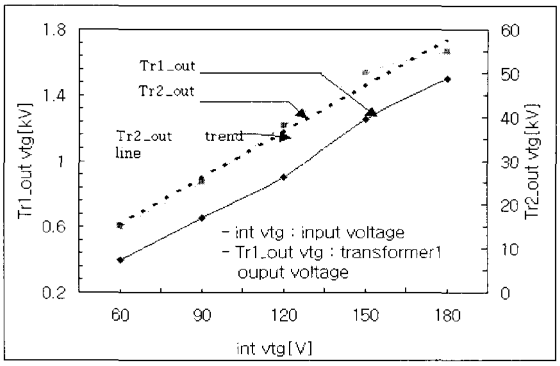


Fig. 6. Voltage increment ratio of Tr1_out and Tr2_ou in the range of AC input voltage from 60V to 180V on using load resistor 24kΩ.

Table 3 provides the T.V and M/T of Tr1_out & Tr2_out.

The average value of Tr2_out, cascading voltage, had about 66% of theoretical value.

Figure 7 shows voltage increment ratio according to load resistors. Adopting the cascading technique to pulse transformer, as a result, we obtained the average cascading voltage increased about 62% of theoretical value compared to not cascading one.

Table 3. T.V and M/T value of Tr1_out & Tr2_out.

Int vtg[V]	Tr1_out T.V[kV]	Tr2_out T.V[kV]	Tr1_out M/T [%]	Tr2_out M/T [%]
60	1.3	26	31	56
90	2	40	33	63
120	2.7	54	33	70
150	3.4	68	37	73
180	4	80	38	69

* T.V : Theoretical Value, M/T : Measured/Theoretical Value

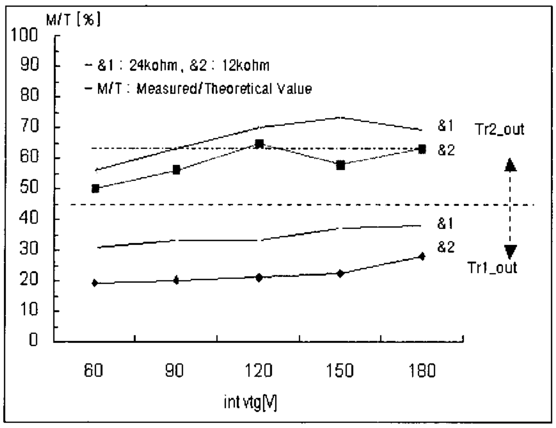


Fig. 7. Voltage increment ratio according to load resistors.

4. Conclusions

On the basis of the pulse generator, we built a compact pulse generator using cascading technique. We could easily obtain high pulse voltage whose peak value was more than 55kV by adopting cascading method. Also, we found that average cascading voltage was almost 62% of theoretical value. Maximum cascading ratio(measured value of cascading voltage/measured of no cascading voltage) was calculated at almost 60. At pulse generator of the cascaded type, even though the same turn ratio of the pulse transformer, there are each different value at Tr2_out M.V (This is measured value at the secondary Tr2) according to the secondary inductance of Tr1 and primary inductance of Tr2. So, we found that transformation of pulse voltage by cascading method was related to each secondary inductnace of Tr1 and primary inductance of Tr2. In conclusion, when pulse transformers of the cascaded type was designed, we have to consider some electrical parameters of the primary inductance of Tr1 and of the secondary one of Tr2.

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