Auxiliary Power Supply for Marx Circuit with Transformers inserted into Charging Path of Marx Capacitors

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In this paper, an auxiliary power supply using its switching operation for gate drivers of a Marx circuit is proposed. The Marx circuit is suitable topology to supply high voltage DC with high d*v* / d*t* because of the connection of multi-stage capacitors and power devices. The power devices used in the Marx circuit has high voltage potential to the ground dues to the series connection of multi-stage capacitors. Thus, the conventional gate drive power supply, which supplies power from the low-voltage side, requires large isolation distance, which typically prevents downsizing. In this paper, an auxiliary power supply for the gate drive circuit using a transformer inserted into the Marx circuit is proposed in order to solve above problem. In a simulation executing on a system with an input voltage of 1 kV and an output power of 500 W, it is demonstrated that a drive power of 1 W or more is supplied through a transformer with a primary value of 10 μH.

Keywords Marx circuit, Pulsed power supply, gate drive, Power supplies

1. Introduction

In recent years, the Marx circuit has been studied for a power supply of an ozonizer [1] because the ozonizer requires a pulsed power supply with high d*v* / d*t*. The Marx circuit is suitable topology as a pulse power supply because of its simple configuration. However, since the power devices and the capacitor are in a cascade configuration, the switching devices on each cell have high voltage potential. Thus, the gate drive circuits have to be bulky due to the isolation distance between the low-voltage side and the high-voltage side [2,3]. Moreover, the high-voltage isolated DC-DC converter may increase the cost of the gate drivers. In this paper, a new topology of supplying gate drive power using a charging operation of the Marx circuit through a transformer inserted into a charging path of capacitors is proposed.

2. Marx circuit and Gate drive power by transformer

Figure 1 shows the operation of a two-stage Marx circuit with a transformer for auxiliary power and the Marx circuit. Note that the actual circuit is composed by many number of stages. however, this circuit is used for explanation simply. The auxiliary power supply supplies power to the gate drive circuit. During the discharging mode, S_2 and S_4 are turned-on, the Marx capacitors are connected in series, and a high voltage is output to the load with high d*v* / d*t*. In the charging mode, switches S_1, S_3, S_5, and S_6 are turned-on, the Marx capacitors are connected in parallel, and the capacitors are charged. In order to obtain high d*v* / d*t*, the Marx circuit should not have an inductance in the discharging path. therefore, the transformers are inserted into the A or B. The transformers of the proposed auxiliary power supply are not inserted into the discharge path, therefore, the proposed auxiliary power supply does not affect the discharging operation of the Marx circuit. In the charge mode, the current flows through the inserted primary coil. A magnetic flux is generated by the current flowing on the primary coil, and the magnetic flux is coupled to the secondary coil to supply power. The power supplied by the transformer is verified by calculation and simulation. Since the current flowing in the place where the transformer is inserted does not change between A and B, the same analysis is performed.

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3. Analysis of Supplied Power

Figure 2 shows the equivalent circuit during charging operation including the transformer. When the time is 0 s, current flows in leakage inductance and mutual inductance. The secondary load voltage is the sum of the voltage of mutual inductance and the leakage inductance. The power supplied to the load is given by the product of the secondary load voltage and the current flowing through the leakage inductance. However, the solution becomes a quartic equation under conditions where the DC voltage fluctuation on the secondary side of the circuit is large (conditions where small

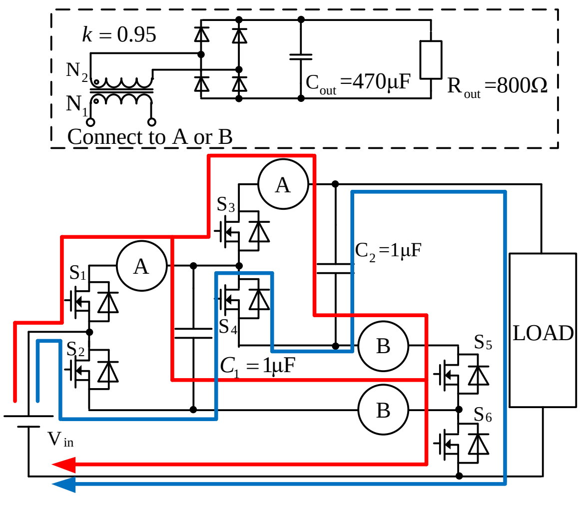

Fig. 1. Two-stage Marx circuit.

capacitor is connected). Further, the secondary capacitor should be enough large because it must supply stable driving power. Therefore, the secondary capacitor is approximated as a constant voltage source for simplicity. The current flowing to the leakage inductance side is represented as:

$$i_{1(t)} = k\frac{V_{in}-V_0}{\sqrt{(\frac{R_{wiring}}{2})^2-\frac{\alpha}{C_1}}}e^{-\frac{R_{wiring}}{2\alpha}t}\sinh\sqrt{\left(\frac{R_{wiring}}{2\alpha}\right)^2-\frac{1}{\alpha C_1}}\,t-kV_{out}t, \tag{1}$$

$$\alpha=(L_{1leak}+L_{2leak}),\quad \beta=(L_{1leak}+L_M)=(L_{2leak}+L_M), \tag{2}$$

where k is the coupling coefficient, V_0 is the initial charging voltage of C_1, R_{wiring} is the wiring resistance, V_{out} is the load-side voltage α is the sum of the primary and secondary leakage inductances, and β is the sum of primary or secondary leakage inductance and mutual inductance. the current flowing to the mutual inductance side is represented by (2–4). The reason why there are two expressions relating to the current flowing through the mutual inductance will be described. A current flow to the leakage inductance side when the sum of the voltages of the mutual inductance and the leakage inductance on the secondary side is higher than the DC voltage on the load side. The voltage of the mutual inductance when the current is flowing to the leakage inductance side is given by

$$i_{2(t)}=\frac{1}{L_m}\int L_{2leak}\frac{di_{1(t)}}{dt}+V_{out}dt\ . \tag{3}$$

If the sum of the secondary leakage inductance voltage and the mutual inductance voltage is lower than the load, current does not flow through the load, so current flows through the mutual inductance regardless of the load. When the sum of the voltage of the secondary side leakage inductance and the voltage of the mutual inductance is lower than the load, the current flowing through the mutual inductance is expressed by

$$i_{2(t)}=\frac{V_{in}-V_0}{\sqrt{\frac{\beta}{C_1}-(\frac{R_{wiring}}{2\beta})^2}}e^{-\frac{R_{wiring}}{2\beta}t}\sin\sqrt{\frac{1}{\beta C_1}-\left(\frac{R_{wiring}}{2\beta}\right)^2}\,t\ . \tag{4}$$

Each voltage on the circuit is obtained by differentiating (1), (3) and (4).

4. Analysis of Supplied Power

The assumed application is a 10-stage Marx circuit with an input voltage of 1 kV and an output power of 500 W. Furthermore, the frequency is 10 kHz. Therefore, the primary capacitor voltage drops by 30 V from the input voltage in a single discharge operation.

Figure 3 shows the waveform of the current that flows to the secondary leakage inductance by the calculation represented by $i_{1(t)}$ and simulation. Figure 4 shows the waveform of the current that flows to the mutual inductance by the calculation and simulation expressed by $i_{2(t)}$. Since the calculation results matched the simulation, the current flowing in the Marx circuit with the transformer that supplies the auxiliary power could be generalized.

Figure 5 shows the relationship between primary inductance and supplied power to the gate driver. In order to supply the minimum power required to drive the gate through simulation and calculation, there is a use where the primary inductance value is 10 μH or more.

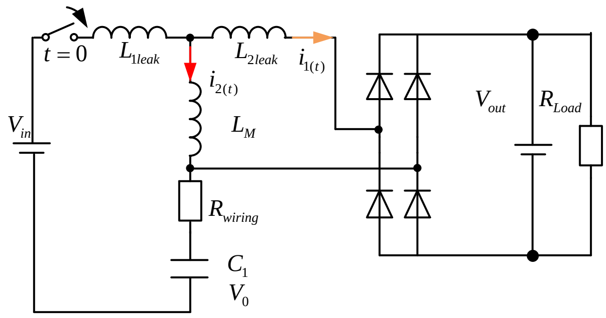

Fig.2. Equivalent circuit for Marx circuit charging operation including transformer for auxiliary power supply.

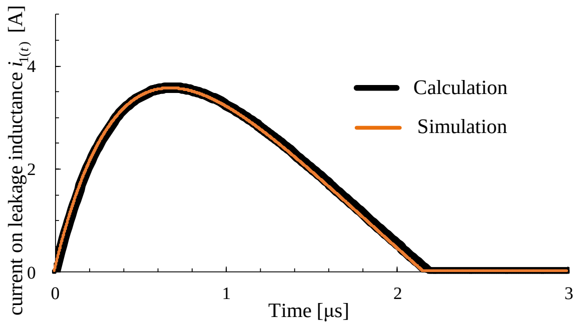

Fig. 3 Current flowing in leakage inductance $i_{1(t)}$.

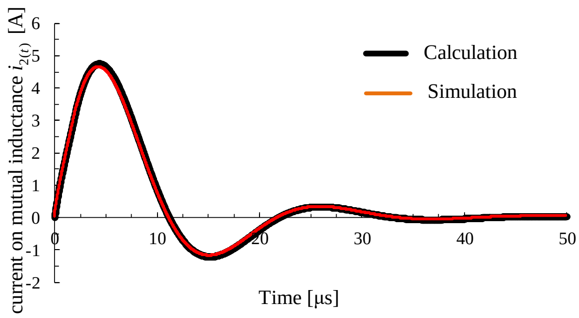

Fig. 4. Current flowing in mutual inductance $i_{2(t)}$.

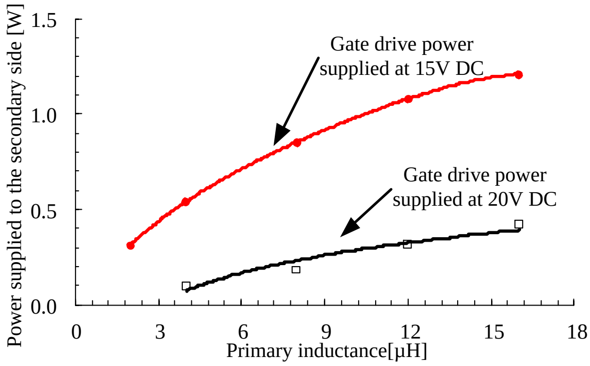

Fig. 5 Relationship between power and inductance.

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