An Isolated Feedback Circuit for a Flyback Charging Circuit

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Abstract: - In a conventional flyback charging circuit with feedback, the input of feedback circuit is usually sampled from the output voltage across a resistive voltage divider. Hence the charging circuit gets unisolated. As isolation problem will cause safety and stability problems to the charging circuit especially when the output voltage gets high, a feedback circuit which samples from the input side of the flyback charging circuit is brought out in this paper in order to solve the isolation problem. The working process is analyzed. And the choice of the parameters of that feedback circuit is introduced. Simulation results are presented to show that the circuit is capable of controlling the charging circuit as well as solving the isolation problem.

Key-Words: - flyback charging, feedback, isolation, transformer

1 Introduction

The flyback charging circuit is widely used in many areas, such as switching mode power supplies, flash lamps and even fuzes. The background of this paper is Electronic Safety and Arming system(ESA) which is used in fuzes[1]. As it is so widely used, researches of different aspects have been well done. The working modes of the circuit which include CCM and DCM have been well known to us[2-3]. Different topologies for different control methods have been studied, such as Pulse Train Control, Adaptive Off-time Control, Packet Control, PWM Control and so on[4-7]. Control algorithm for optimal charging is also referred[8]. Auxiliary part of the flyback charging circuit has been developed for some special purposes such as minimization of power loss as well as minimization of spike voltage on the transformer primary side[9]. All of these researches have greatly improved the performance of flyback charging circuit. However, as far as our knowledge goes, there are few thesis that touch the isolation problem between the input and output side of the charging circuit when a feedback circuit is used[10]. But in ESA, in order to ignite the detonator, the output voltage of the flyback charging circuit has to get up to 3000 volts. This high voltage in the output side may cause some safety and stability problems when the circuit is not isolated between the input and output side. In this paper, in order to solve the isolation problem while a feedback circuit is used, a feedback circuit which samples from the transformer primary side is brought forward.

2 Problem Formulation

The circuit diagram of a conventional flyback charging circuit with feedback is shown in Fig.1. As it is shown in Fig.1, the existence of the transformer makes the isolation of the input side from the output side of the charging circuit possible. But the feedback circuit connects the two sides by the sampling across a resistive voltage divider.

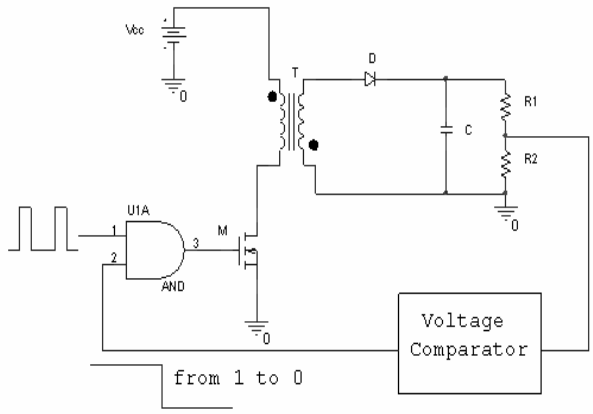

Fig.1 A fly-back charging circuit with feedback

As the output of the feedback circuit always have to be sent to the input side of the charging circuit, there are two different ways to solve the isolation problem:

1. Isolating the input from output of the feed-back circuit.

2. Sampling from the input side of the charging circuit.

2.1 Photoelectric Coupling

Usually, photoelectric coupling is used for the isolation purpose. In order to isolate the input from output side of the feedback circuit, as shown in Fig.2, a photoelectric coupling is used.

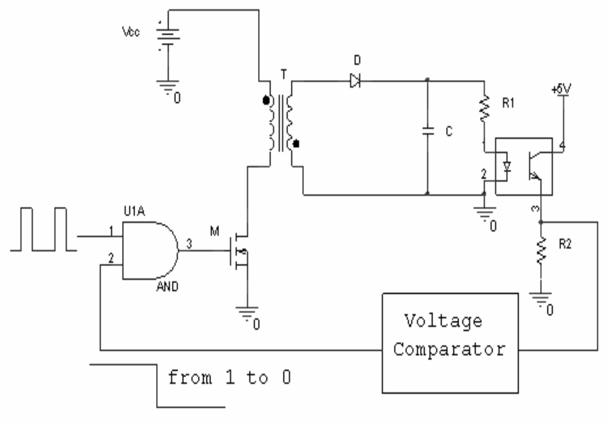

Fig.2 Feedback circuit using photoelectric coupling for isolation purpose

Obviously, by applying photoelectric coupling, the input and output of the feedback circuit are isolated. The problem is that the resistance of the voltage divider is very high in order to reduce its power loss, hence the current through R_1 is too small to drive the photoelectric coupling. So this method is not appropriate to solve the isolation problem.

2.2 Sampling from the Input Side

Because there are some difficulties in solving the isolation problem by applying photoelectric coupling, we thus turn to the second method to get the sample from the input side of the charging circuit.

In the following sections, we begin with discussing the working process of the flyback charging circuit as well as some waveforms during its working stages.

2.2.1 Working Mode of the Flyback Charging Circuit

Firstly, we list out the following symbols which are laterly used :

Drain-to-Source voltage of MOSFET M	U_S
Drain-to-Source current of MOSFET M (Transformer primary-winding current)	I_S
Current through diode D (Transformer secondly-winding current)	I_D
Time of a working cycle	T_S
MOSFET on time in each working cycle	t_{on}
MOSFET off time in each working cycle	t_{off}
Transformer primary-winding	W_1
Transformer secondly-winding	W_2
Transformer primary turns	N_1
Transformer secondly turns	N_2
Source voltage(input voltage)	U_i
Energy-storage capacity voltage	U_O

During the work of the fly-back charging circuit, there are 2 kinds of working modes: Continuous Conduction Mode (CCM) and Discontinuous Conduction Mode (DCM)[2].

When the flyback charging circuit works under continuous conduction mode, there are two stages in each working cycle. The waveforms are shown in Fig.3.

t_0--t_1 (energy-storing stage):After the MOSFET is turned on, U_S changes to a value near zero. I_S increases over time and I_D keeps zero. The starting value of I_S is not zero. Energy stored in the transformer primary winding increases over time.

t_1--t_2 (charging stage):After the MOSFET is turned off, the transformer begins to transfer energy to the energy-storing capacitor C through diode D. The current I_D induces a reverse voltage in the transformer primary winding, hence the Drain-to-Source voltage after the MOSFET is turned off is as follow:

$$U_S = U_i + \frac{N_1}{N_2} U_O \qquad (1)$$

When the MOSFET is turned on again, because the energy stored in the transformer has not been totally transferred to the capacitor, I_D will not decrease to zero.

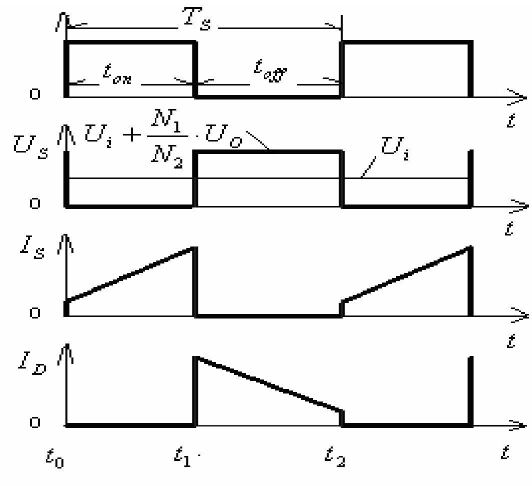

Fig.3 Waveforms under CCM

While the flyback-charging circuit works under discontinuous conduction mode, there are three stages in each working period. The waveforms during the charging process are shown in Fig.4.

t_0--t_1(energy-storing stage):The process of this stage is just like the energy-storing stage under CCM. The difference is that the starting value of I_S is zero.

t_1--t_2(charging stage): The process of this stage is just like the charging stage under CCM. The difference is that the ending value of I_D is zero. During this charging stage, the Drain-to-Source voltage is:

$$U_S = U_i + \frac{N_1}{N_2} \cdot U_O \qquad (2)$$

t_2--t_3(idle stage):Input and output current of the transformer take zero. And the Drain-to-Source voltage keeps at the value of U_i.

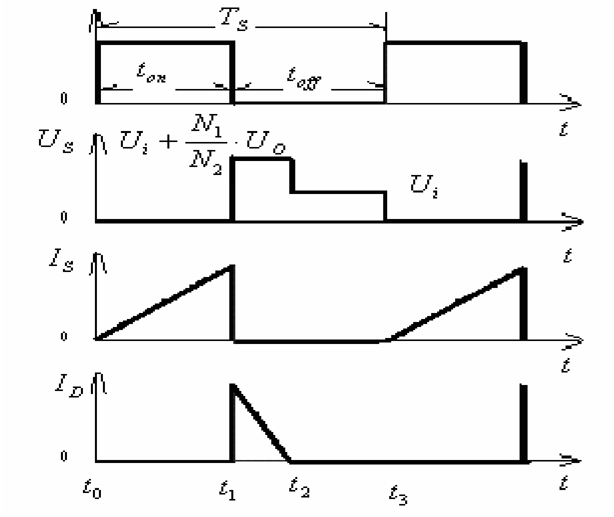

Fig.4 Waveforms under DCM

2.2.2 The Use of U_S in Isolated Feedback

During the previous analysis of the waveforms under both CCM and DCM, much attention are paid to the change of U_S, hence some useful information are detected.

The equations (1) and (2) are the same. And according to the equations, under both CCM and DCM, there are some connections between the Drain-to-Source voltage U_S and the energy-storing capacitor voltage U_O during the charging stage. That means if we get the value of U_S during the charging stage, by solving the equation (1), the value of U_O is determined uniquely.

Fig.5 shows the simulation waveforms of U_O and U_S. The upper part of Fig.5 is the waveform of U_O, while the lower part shows the waveform of U_S.

By comparing these two waveforms, we can see clearly that the outline of the waveform of U_S shares the same shape with the waveform of U_O during the charging process.

The connection between U_S and U_O enables the isolated feedback which samples from the input side of the charging circuit. But there are some problems with the use of the voltage U_S.

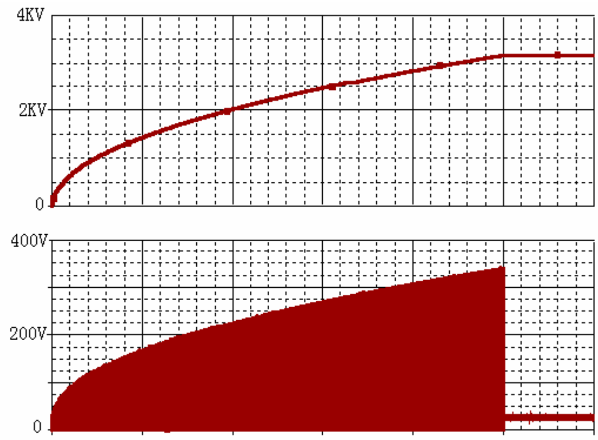

Fig.5 Simulation waveforms of U_O and U_S

The U_S has the connection with U_O only at the charging stage, while during other time periods of each working cycle, the connection dose not exist any more. So we can not get the useful part of U_S directly from the charging circuit. How the U_S should be sampled? It is the first question.

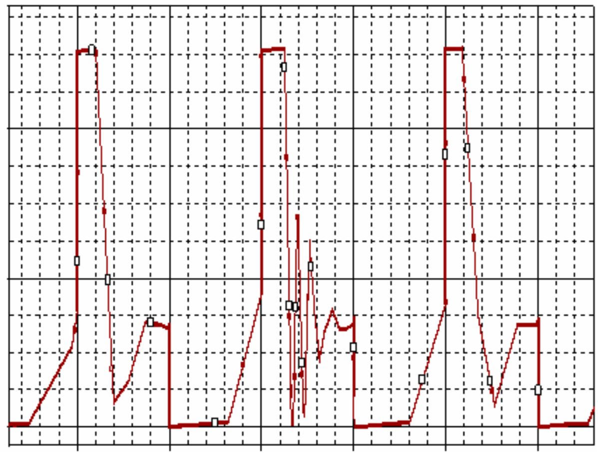

Fig.6 Detailed simulation waveforms of U_S

Fig.6 shows a detailed simulation waveform of U_S under discontinuous conduction mode. The waveform confirms that the connection between U_S and U_O described by equation (1) only exists during the charging stage of each working cycle.

In addition, after the charging process stops, the value of U_S will not have any connection with U_O but keeps at the value of U_i. This can be seen clearly from the simulation waveform of U_S which is shown in Fig.5. So, during the discharging process, we can not get the value of U_O by measuring U_S. In what way can the circuit be under control during the discharging process? This is another question.

3 Problem Solution

At the end of 2.2.2 , two questions of how to use U_S are raised. A simple circuit topology is put forward in this section to solve those problems. It is shown in Fig.7.

The working process of the feedback circuit is like that: During the charging stage of each working cycle, the charging current in W_2 induces the voltage U_S which is described by the equation (1), hence the diode D_2 allows current to flow through it. The capacitor is then charged to the value of U_S. At other times of each working cycle, diode D_2 is off, current flows through C_2, R_2 and R_3. If the charging process is quick enough and the discharging process is slow enough, the voltage of C_2 will keeps the value around $U_i+(N_1/N_2)\cdot U_O$. When the charging process stops, the voltage of C_2 will decline slowly. And the speed of the voltage declining is determined by the value of C_2, R_2 and R_3.

If R_{D2f} is the forward resistance of diode D_2, then the charging time constant of the feedback circuit is:

$$\tau_1 = R_{D2f} \cdot C_2 \qquad (3)$$

And the discharging time constant is:

$$\tau_2 = (R_2 + R_3) \cdot C_2 \qquad (4)$$

In order to keep the voltage of C_2 around the value of $U_i+(N_1/N_2)\cdot U_O$ as closely as possible during the charging process, τ_1 should be tiny enough and τ_2 should be much larger than τ_1.

Additionally, in order to minimize the influence that the feedback circuit has brought to the charging circuit, the current which is required to charge the capacitor C_2 should be limited. So, the capacitance of C_2 should be neither too large nor too small.

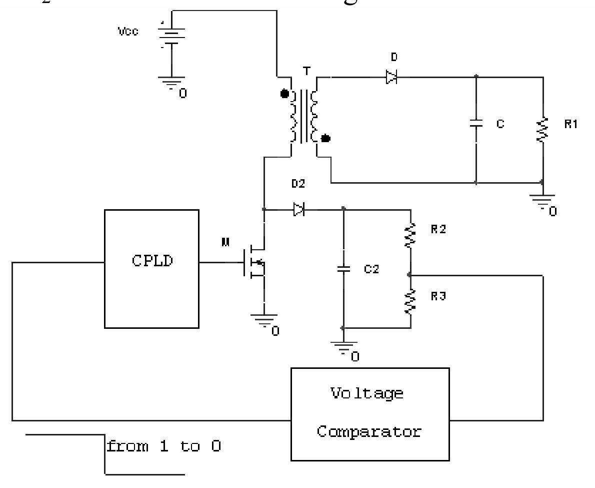

Fig.7 The feed-back circuit which gets its input from the input side of the charging circuit

The waveforms shown in Fig.8 are simulation waveforms of the circuit shown in Fig.7. The upper part shows the voltage of the energy-storing capacitor C_1, while the lower part shows the voltage of C_2, which is used as the sampling voltage of the feedback circuit.

As shown in Fig.8, during the charging process, the waveforms of the voltage of C_2 and the voltage of the energy-storing capacitor are the same in shape.

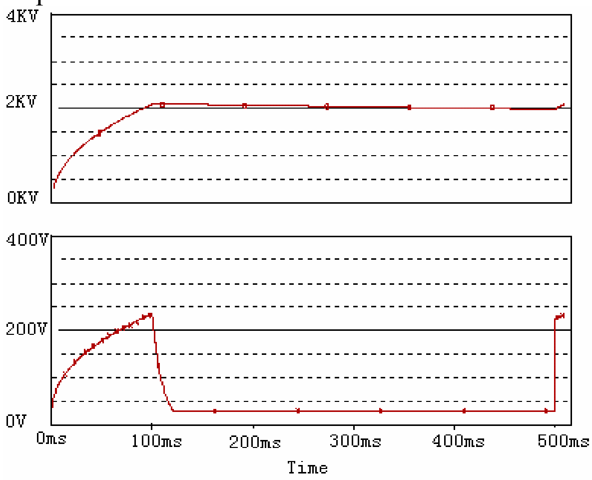

Fig.8 Simulation waveforms

The connection between their values is described by the equation below:

$$U_{C2} = U_i + \frac{N_1}{N_2} \cdot U_O \qquad (5)$$

where U_{C2} represents the voltage of C_2, U_i=27V and N_1/N_2=1/10.

When the charging circuit stops charging the energy-storing capacitor C_1, U_{C2} decreases, and the connection between the value of U_{C2} and U_O is not available any more. But when the charging process starts again, U_{C2} rises quickly to the value of $U_i+(N_1/N_2)\cdot U_O$.

If it is required that $U_O \in (U_{O1}, U_{O2})$ during the charging process, U_{C2} should be within $(U_i+(N1/N2)\cdot U_{O1}$, $U_i+(N1/N2)\cdot U_{O2})$, then the threshold of the voltage comparator should be:

$$(U_i + \frac{N_1}{N_2} \cdot U_{O2}) \times \frac{R_3}{R_2 + R_3}$$

So, when U_O rises to the value of U_{O2}, the output of the voltage comparator will change from 1 to 0.

Time delay control method is used when the charging process is paused. When the CPLD gets the information that the output of voltage comparator changes from 1 to 0, it will control the charging circuit to stop charging. After a period of time, the CPLD controls the charging circuit to restart charging. When U_O rises to U_{O2} again, the output of voltage comparator will again change from 1 to 0, then another cycle begins. The length of the delaying time should be chosen properly to ensure that U_O keeps higher than the value of U_{O1}.

Till now, those two questions have got their answers.

4 Conclusion

In this paper, a feedback circuit has been presented and analyzed in order to solve the isolation problem between the input and output side of the flyback charging circuit. Simulation results show that this circuit is capable of controlling the charging circuit if the parameters are chosen properly. By sampling from the input side of the charging circuit, this feedback circuit makes the input and output side of the charging circuit totally isolated. For a flyback charging circuit in fuze, we have to make the charging process as fast as possible, to choose a proper control method and to make the circuit stable. So we still have much work to do. Experiments have to be done to confirm the function of this feedback circuit. In addition, we have to optimize the parameters of the circuit as well as the control method.

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