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Design and Investigation of High Voltage Isolated Silicon-Controlled Rectifier (SCR) Gate Driver

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Abstract: The present article examines the design and implementation specifics of High Voltage Isolated Driver for control of serially connected SCR. The driver features the use of current transformers for the impulses applied to the control electrodes of simple-connected primary coils, as well as control pulses transmission through optical fibre. Results from the experimental study are provided.

Keywords: Silicon-Controlled Rectifier, Driver, High Voltage Isolation

1. Introduction

The correct and reliable operation of the controlled rectifiers depends to a great extent on their management system operation, part of which are the thyristor control drivers [1]. The latter must provide control pulses with the required waveform and parameters at minimum power loss on its elements. The available literature describes generally drivers when using pulse voltage transformers [2]. A summary of the possible solutions for different devices has been made in [3]. In practice high supply voltages require serially connected thyristors, which imposes also the corresponding requirements to their control drivers. A more systematic consideration of the possible circuit solutions is presented in [4]. The control of serially connected thyristors is described in [5]. A driver for serially connected thyristors, using current transformers, is proposed in [6]. The proposed connection of primary coils is complicated and creates implementation difficulties.

This article describes the specificities of driver design and implementation for serially connected thyristors, based on current transformers with common primary coils and simplified connection. Each of them consists of a wire, passing through the transformers' cores in different direction. Part 2 of the article proposes a complete circuit diagram and driver operation description, while part 3 is dedicated to current transformers' design and implementation. Part 4 shows the results from the experimental study of the driver.

2. Operation Description

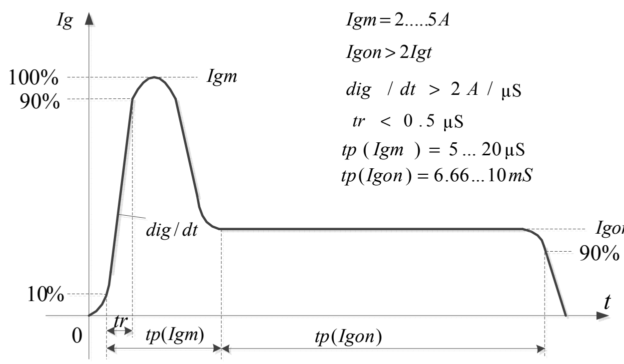

Figure 1. *Requirements to the control pulse waveform.*

The requirements to the control pulse waveform for the particular thyristor type T123-160 are shown on fig.1 [7]. They are typical for all rectifying thyristors. Fig.2 presents a schematics of the driver. For the control of each thyristor are used two current transformers - CTr1 and CTr2. Both wires forming the primary coils pass through the cores of the transformers in different direction, as shown on fig.2. Therefore, when the current flows through one of the primary coils, the voltages of the secondary coils have different polarity. Thyristor enabling pulse of an approximate level 0V is obtained at the output of the optical receiver HFBR-2524 [8], inverted by transistor VT1 and applied at the input of a driver integrated circuit TC4422 [9]. Thus, for the control pulse duration the transistor VT3 is enabled and the current I_{PULSE} flows through the current transformers primary coil connected with $R10$. The initial peak of the control current I_{gm} for time $tp(I_{gm})$ is ensured by current transformer 1 (CTr1), while the current I_{gon} for time $tp(I_{gon})$ is provided by current transformer 2(CTr2).

During the thyristor control pulses pause, the transistor VT2 is enabled also via driver integrated circuit TC4422. The current I_{PAUSE} flows through the primary coil, connected with $R9$ and demagnetizes the current transformer coils. Blocks 2, 3 and 4, shown on fig. 2, contain the secondary coils and the elements thereof for thyristors VS2, VS3 and VS4 respectively.

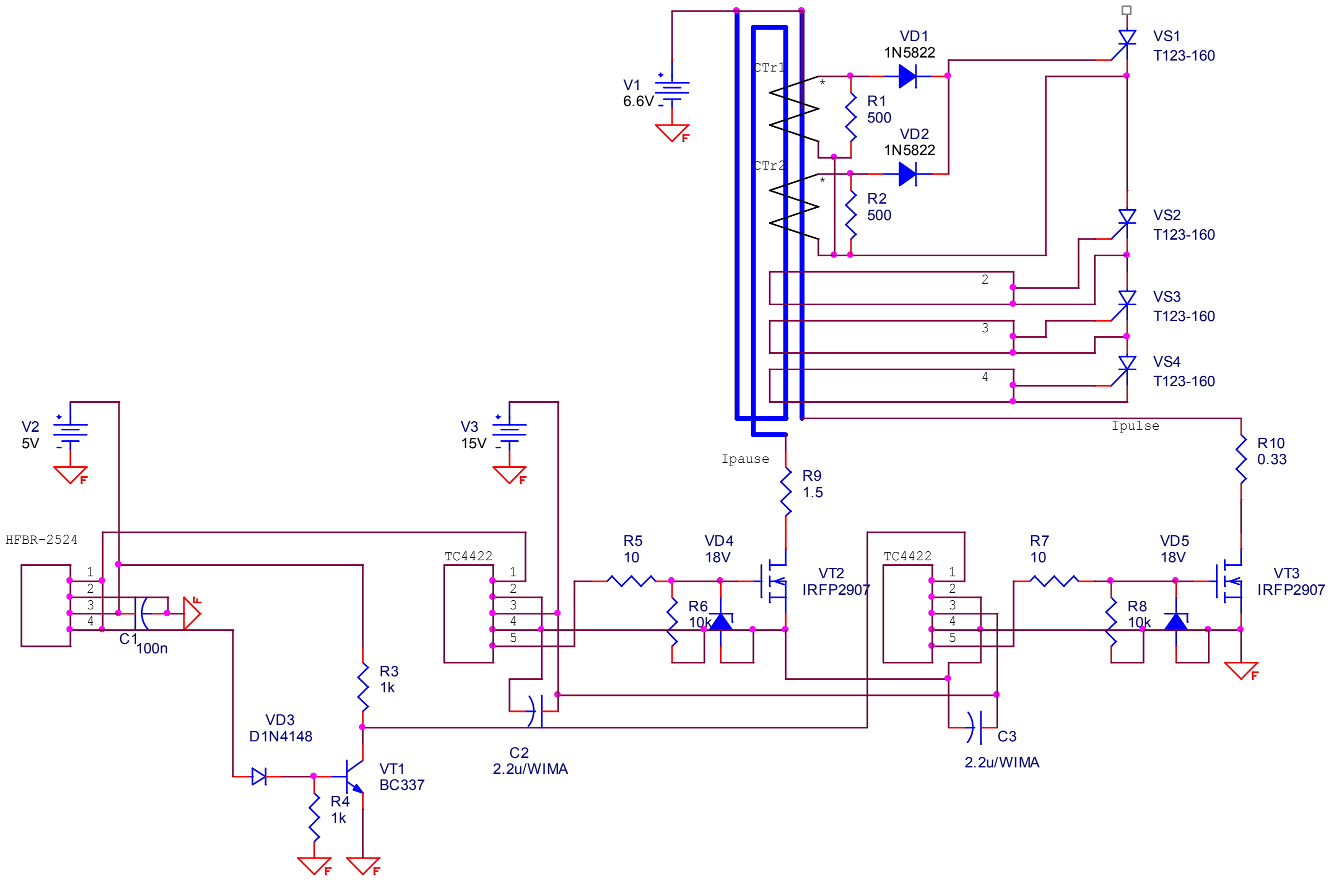

Figure 2. *Driver circuit diagram.*

3. Design and Implementation Specifics of Current Transformers

The output data for transformers design result from the thyristors input characteristics and the default values of the amplitude I_{gm} and the plateau I_{gon} of the thyristor control current and their durations, according to fig.1. To these currents correspond certain voltages on the control electrode of the thyristors, indicated as U_{gm}, respectively U_{gon}.

The amplitude value of the control current is produced by the current transformer, conditionally designated as CTr1, and the plateau – by the current transformer - CTr2.

The current transformer CTr1 has a more important function - it has to provide not only big amplitude of the control current, but also a steep rising edge. This can be effectively achieved by using high quality magnetic core, for example from an amorphous alloy or even better from nanocrystalline soft magnetic alloy. Ferrite magnetic cores can also be used, but they are not effective enough.

The current transformer CTr2 has the tough job to provide long-duration control current, which in this case it is assumed to exceed the normal duration of thyristors on-state – 6,66mS. It is appropriate to be implemented with magnetic core made of high quality electrical steel.

The shape of the magnetic core and that of both current transformers is chosen to be toroidal in order to achieve the best performance. The size of the internal diameter should be such that after laying their secondary coils, there should remain sufficient space for the primary coil and the insulating barrier between both coils.

In order to synthesize the construction of the considered transformers, the material of their magnetic cores need to be selected and in particular the magnetic induction at which they can operate – B. The value of the current through the primary coil of the current transformers I_{1m} should be also selected.

The number of the transformers secondary coils is determined by the expression:

$$\text{For CTr1 - } w_{21} = \frac{I_{1m}}{I_{gm}} \tag{1}$$

and for CTr2 respectively

$$w_{22} = \frac{I_{1m}}{I_{gon}} \tag{2}$$

The section of the transformers' A_e magnetic cores is determined by an expression, giving the relationship between the voltage on the control electrode at the respective current, the current flow duration and the magnetic induction with which the respective magnetic core can operate.

$$A_e = \frac{U_g t_p}{2 w_2 B} \tag{3}$$

In the case of the discussed sample, transformer CTr1 has a secondary coil of 7 windings and a magnetic core of nanocrystalline alloy with section $0{,}1.10^{-4}m^2$, while transformer CTr2 has a secondary coil with 40 windings and electrical steel magnetic core section of $4{,}5.10^{-4}m^2$. The current through the primary coils of both transformers, while generating control pulse, is equal to 20A. The demagnetizing current does not exceed 5A.

4. Experimental Investigation

The driver thus presented is used for the implementation of a rectifier with output voltage 6.5 kV and current up to 30 A. The supply voltage of the rectifier is 3x 4.5 kV. A three-phase bridge circuit has been used, each thyristor consisting of 4 serially connected thyristors as shown on fig. 2. All four thyristors form a driver controlled thyristor block.

Fig. 3 shows a photo of one of the thyristor blocks together with the current transformers and the elements in their secondary coils.

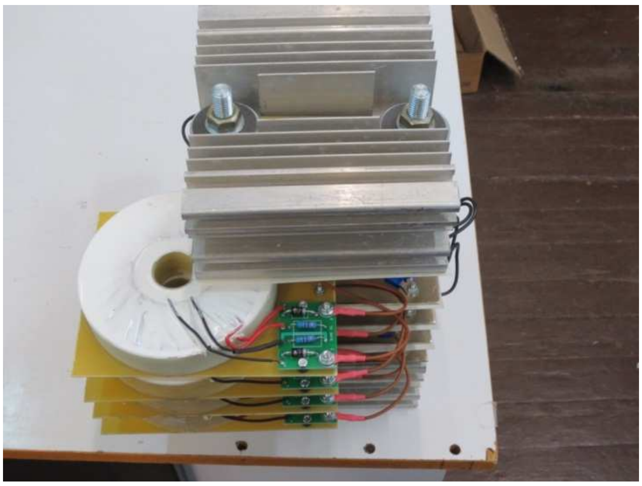

***Figure 3.** General view of a thyristor block with the current transformers and the elements thereto.*

Fig. 4 shows 3 drivers (for one of the rectifier thyristor groups - anode or cathode), together with the power supplies elements. Fig.5 shows the experimentally captured control pulse waveform for one of the serially connected thyristors. The waveform of the current is with ratio 100mV/A.The measured parameters of the controlling pulse are as follows:

$$I_{gm} = 2.5A;\ I_{gon} = 400mA;\ {}^{dig}/_{dt} = 2.5\,{}^{A}/_{\mu S};\ t_r = 0.4\mu S;$$

$$t_p(I_{gm}) = 20\mu S;\ t_p(I_{gon} = 6.7mS)$$

***Figure 4.** General view of the drivers for one thyristor group together with the power supplies.*

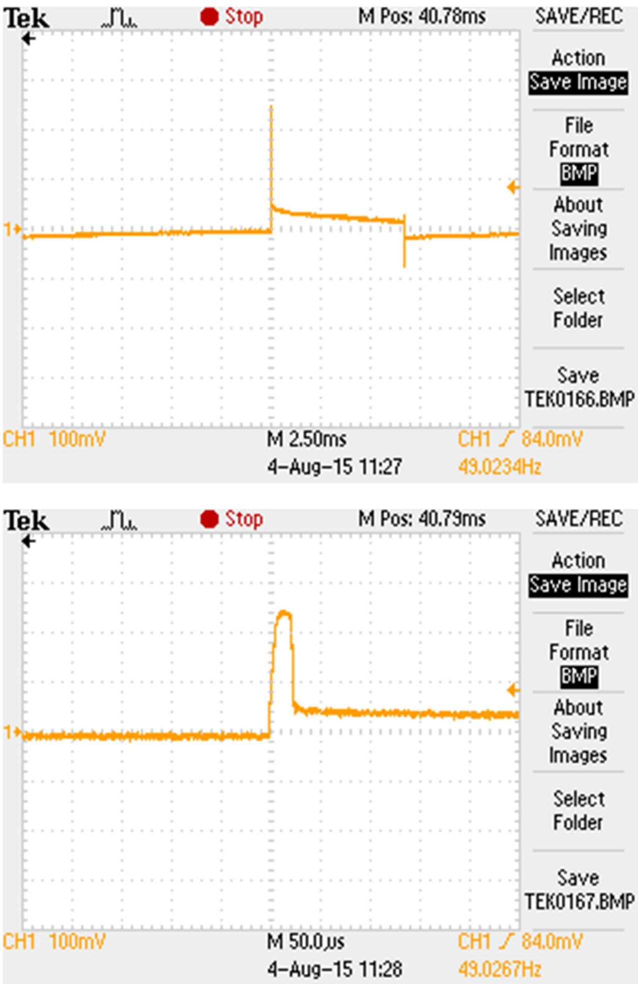

***Figure 5.** Experimental control pulse waveform for one of the thyristors.*

5. Conclusion

The present article describes a high voltage isolated driver for serially connected thyristors, using current transformers. A special feature of the transformers is the simplified construction of the primary coils, consisting of a single wire each. Each thyristor uses two current transformers, one of which transmits the initial peak of the controlling short duration pulse, and the other – the set value of the longer duration controlling pulse. The experimental investigation and the use of the proposed driver in a controlled thyristor rectifier with 6.5kV output voltage and 30A current, show that the required control pulses waveform and reliable operation have been achieved.

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