THYRISTOR SELF-SUPPLIED GATE DRIVE FOR MEDIUM-VOLTAGE CONVERTER RECTIFIER WITH REDUCTION OF SPARE PARTS FOR FIRING

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Abstract – It will be proposed the development of control for thyristor self-supplied gate drive for medium-voltage converter rectifier. It shall be presented a topology intended to minimize the circuit spare parts keeping the characteristics of firing control and thyristor state detection on conduction and blocking. To evaluate the circuit performance it will be presented simulation and experimental results.

Index Terms — Self-supplied gate drive, medium voltage, power converters.

I. INTRODUCTION

The power thyristors have had a rapid commercial acceptance in power control applications since the 50s. Nowadays those switches are normally employed in rectifying circuits that demand DC link voltage control and solid state for starting of AC motors. Due to increasing demand for high power applications, since the end of the 70s, it has been showed a concerning for solid state switches capable of blocking high voltage levels. In the case of power thyristors, in two decades the blocking voltage level was increased by twice and, nowadays, it’s approximately equal to 8 kV [1].

In the case of frequency inverters, it has been noted an increasing demand for AC motor drives in medium voltage applications. However, the demand for insulated sources with high voltage level for gate drives energy supplying has been an inconvenient to use medium voltage switches. A solution that has been adopted is based on gate drive circuits that use energy provided through the snubber circuit and stored in capacitors. This eliminates the needs for insulated sources and reduces, considerably, the volume and cost of medium voltage applications.

In [2–3] it’s presented a self-supplied gate drive applied to thyristors used on a single-phase controlled rectifier and a solid-state starter, both in medium voltage, but do not present the control circuit. This gate drive uses the current that flows through the snubber circuit and store energy in capacitors eliminating the necessity of insulated supply sources.

This same solution was used in [4], but including some electronic components on power circuit. The principle operation of the power circuit is the same as proposed in [2–3]. However, it’s emphasized both the logical circuit, the command of control pulses and the protection against undesirable firing. The logical circuit and the command of control pulses were constituted for many active components and were placed in the same board of gate drive. The inclusion of too many components turns the system more complex and too big, depending on the amount of thyristors to be used. Also it’s used breakover diodes to promote the protection against undesirable firing caused by over-voltage across the power switches.

A similar solution was adopted by BBC [5]. This solution had protection against firing caused by high voltages, high dV/dt during the recovery time, switch state detection on conduction / blocking and short-circuit fault. The principle operation is similar to that presented in [2–4] with the use of breakover diodes to fire the thyristor when the voltage exceeds the breakover voltage, only presented in [4].

In this study it will be adopted the topology proposed in [2–3], but it will be emphasized the reduction of spare parts components [4] for firing power thyristors. The evaluation of its performance will be done through simulation and experimental results.

II. SELF-SUPPLIED GATE DRIVES WITH COMPONENT REDUCTION

The self-supplied gate drives use the current that flows through the snubber circuit to store energy in capacitors. The main function of snubber circuit is employed to reduce the switching losses and provide protection against over-voltage which may cause undesirable firing [6]. A simple snubber circuit consists of an arrangement of series connected resistors and capacitors, which are connected in parallel to the thyristors.

At the time instant when the thyristor is switched off, its conduction current is deviated to the snubber capacitor to store energy in capacitors. The main function of snubber circuit is employed to reduce the switching losses and provide protection against over-voltage which may cause undesirable firing [6]. A simple snubber circuit consists of an arrangement of series connected resistors and capacitors, which are connected in parallel to the thyristors.

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At the time instant when the thyristor is switched off, its conduction current is deviated to the snubber capacitor through the snubber resistor. This will charge the snubber capacitor. During the thyristor switch on, the energy that was stored at the capacitor is dissipated as heat on the resistor. To use the high voltage across the thyristor it has been developed self-supplied gate drives that use capacitors as energy storage elements.
A. Firing Power Circuit – FPC

The power circuit based in [2–3] is presented in Fig. 1. During the thyristor switching off, the current flows through the snubber capacitor and storage capacitor $C_g$ up to the moment that the voltage across $C_g$ is higher than the $D_z$ zener diode breakdown voltage, Fig. 2(b). During the negative semi-cycle the current flows through the snubber circuit by diode $D_1$, Fig. 2(c). When it’s applied a command to switch on the thyristor, the energy stored at capacitor $C_g$ will supply the gate drive system, Fig. 2(d).

The snubber dimensioning is done through the balance between the charge stored at the storage capacitor and the charge used by the thyristor switching. This balance is presented at (1).

$$C_{\text{smu}} \cdot V_{\text{source}} = C_g \cdot V_{cg} \tag{1}$$

, where:

$V_{\text{source}}$ is the voltage across the snubber capacitor,

$V_{cg}$ is the voltage variation across the storage capacitor.

So for $C_g = 470 \mu F$ and $V_{\text{dual}} = 311V_{p-p}$, the voltage variation across $C_g$ has a ripple approximately equal to $0.4V_{p-p}$.

The equivalent snubber capacitance is calculated in (2). To guarantee the snubber circuit performance, $C_g$ has to be much greater than $C_{\text{smu}}$.

$$C_{\text{equiv}} = \frac{C_{\text{smu}} \cdot C_g}{C_{\text{smu}} + C_g} \tag{2}$$

B. Logical Circuit

The logical circuit have function of a simple firing switch. It only receive the command pulses of an external circuit through optical fiber receiver, $FO1$. At this way, the generation and control of command pulses are done externally by a control board, what reduces the amount of active components in the logical circuit, as shown in Fig. 3. Consequently the charge consumption will be reduced, since this active components use the same energy stored at capacitor $C_g$.

The monitoring of the thyristor operation state is done through the comparison between the voltage across the gate resistor $R_{gate}$ and the voltage across the diode $D_{med}$, both shown in Fig. 3. When the thyristor is fired by the pulsed signal, the voltage waveform across the gate resistor $R_{gate}$ shows average and oscillating components. The average value is approximately equal to $0.7V$, which represents the voltage across gate-cathode. Due to this particularity, it’s proposed the state operation monitoring by this signal through an optical fiber $FO2$. Thus this signal will be processed by the board that generates the firing signals. In this board it will be determined if the thyristor is conducting or blocked.

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At thyristor turn on, it will be sent a continuous signal during all conduction cycle by $FO_2$. When the thyristor do not turn on, although it has been generated a firing command, the signal to be sent by $FO_2$ it will be the same command signal generated by control board, in other words, the pulsed signal.

This strategy reduces spare parts of active components that are needed to evaluate the thyristor state, which in turn reduces the charge that would be drained by gate drive. Thus the firing / control routine will be embedded on the board that commands the thyristor firing pulses.

III. RECTIFIER BRIDGE FOR THE MEDIUM VOLTAGE INVERTER

The objective of the self-supplied gate circuit is the development of a 12 pulses rectifier bridges to supply the DC link of a neutral clamped medium voltage inverter. As shown in [7], it will be used a rectifier bridge provided with a protection scheme that blocks the thyristor gate pulses, which is called PSP. This protection scheme shown to be more efficient than the classical solutions based on fuses, protection IGCT’s and crowbar circuits.

IV. RESULTS AND ANALYSIS

As case study, it will be shown the simulation and experimental results of a thyristor connected in series with a resistive load in low voltage, as can be seen in Fig. 5. The Fig. 6(a) was obtained through simulation and shows that the voltage across the storage capacitor takes, approximately, 145ms to reach the zener diode breakdown voltage. This same result is observed at the experimental curve shown at Fig. 6(b). After this time, the gate drive is ready to operate.

This method is implemented through a short-circuit on the DC link and on the blocking of the thyristors gate pulses of the rectifier bridge when the $di/dt$ limiting circuit detects a current greater than that specified.

Each switch of the rectifier bridge is built through a series arrangement of three thyristors as shown in Fig. 4. The thyristors to be used in the bridge are the Aegis Semiconductors A5N:300.18H. For this application, the thyristor state detection circuit will not be present in the gate drive, but instead the state detection will be performed by the evaluation of the DC link voltage. This strategy reduces the amount of components the on the gate drive.
The current in the snubber circuit and storage capacitor is presented at Fig. 7. As observed at this figure, the current through the storage capacitor is the same observed at the snubber circuit during the positive half cycle. This happens until the capacitor is charged and reaches the maximum voltage of the zener diode, $D_z$.

Fig. 8 presents the voltage across the storage capacitor and the gate current. As can be seen in this figure and also in details at Fig. 9, at steady state, the voltage across the storage capacitor reaches a medium value equal to 2.7 V with a ripple equal to 0.4 V. Fig. 8 also shows that the voltage capacitor transient time lasts 200ms, which is determined by the time constant related to the association between the snubber and storage capacitors and the snubber resistance.

Figs. 10(a) and (b) show the voltages across the load resistor $R_{load}$ and gate resistor $R_{gate}$. Those figures indicate the gate drive is firing the thyristor.

Since in the study related to the half-cycle controlled rectifier the simulation results were verified experimentally, it will be presented only simulation results concerned to a 12 pulses controlled rectified with line voltage equal to 2200V.

The storage capacitor voltage takes approximately 170ms to reach the zener diode maximum voltage, as can be seen at Fig. 11. The gate current and the storage capacitor voltage observed during the conduction state of the thyristor is presented at Figs. 12(a) and (b). The average value of the storage capacitor voltage is approximately 3.5V, what is reached when the energy provided by the snubber circuit is equal to the energy demanded by the gate drive.
As can be seen, the waveforms presented at Figs. 12(a) and (b) are similar to those presented at Fig. 8, whose were obtained for the test circuit presented at Fig. 5.

![Figure 11](image1.png)

**Fig. 11** – Voltage across the storage capacitor for 12 pulses controlled rectified bridge (simulation)

![Figure 12](image2.png)

**Fig. 12** – Voltage across the storage capacitor and gate current for 12 pulses controlled rectifier bridge (simulation)

### IV. CONCLUSIONS

It was proposed a gate drive with reduce spare parts to build the firing switch.

The circuit performance was evaluated by experimental results obtained from a single thyristor operating at low voltage and by simulation results related to a 12 pulses rectifier bridge.

### REFERENCES


