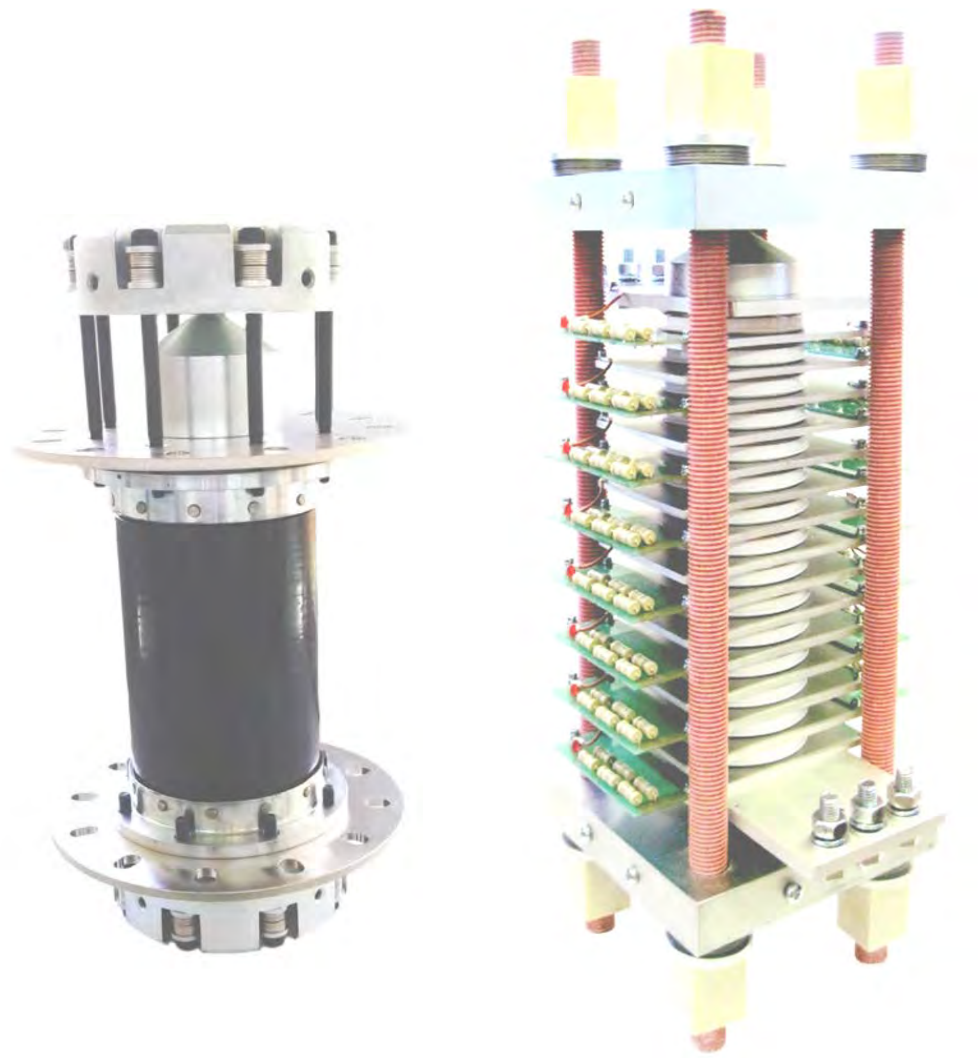
Power semiconductor devices for pulse applications

COMMUTATORS ON THE BASE OF REVERSE-SWITCHED DYNISTORS

Application notes



Contents

1 General description of reverse-switched dynistors (RSD)

1.1 Introduction

Solid state semiconductor switches are widely applied in power systems pulse supply. They substitute gas-discharge devices (ignitrons, thyratrons, spark-gap and vacuum dischargers) in laser and accelerating units, roentgenoscopy, technological equipment (separation, cleaning and other). Semiconductor switches have long operation period, low operating costs, ecological safety (no mercury and lead). They can operate by any space orientation, hence may be applied both in stationary and mobile equipment.

Conventional thyristors (SCR) are most often applied in pulse equipment. However, conventional thyrisrors reveal their disadvantages by commutation of short pulses with high current magnitude and high di/dt (≥ 10-20 kA/μs). It is conditioned by slow spreading of on-state area after triggering pulse application that leads to high switching losses. Switching losses can be lowered by means of interdigitated gate. But this measure leads to essential loss of device active area (up to 50-80%).

Switches on the base of RSD are very effective by commutation of high current pulses in duration range from few microseconds up to some hundreds microseconds. RSDs have very low conduction losses and high blocking capability, and contrary to thyristors are turned-on homogeneously at all active area like power diode. These properties allow RSD commutators (RSD-DS) with operation voltage of some dozens kV to commutate hundreds kA with ultra-high current rate of rise (≥10^5 A/μs). Operation by relative low current magnitudes and di/dt (50-80% from maximum values) provides very high RSD-DS reliability.

1.2 Type designation

1.2.1 Designation example of high voltage commutator for single pulse operation mode.

KRD 1 – 250 – 25

- Commutator type (KRD – commutator on the base RSD)
- Commutator design variant:
  (1 – RSDs are connected in series in single case from robust fiberglass; 2 – standard high voltage stack type BipSTACK)
- Operation voltage (V_{DRM}), kV (25 – V_{DRM} = 25 kV DC)
- Pulse operation current (I_{pw}), kA (250 – I_{PW} = 250 kA)

1.3 RSD-based switch design

1.3.1 Reverse-switched dynistor design

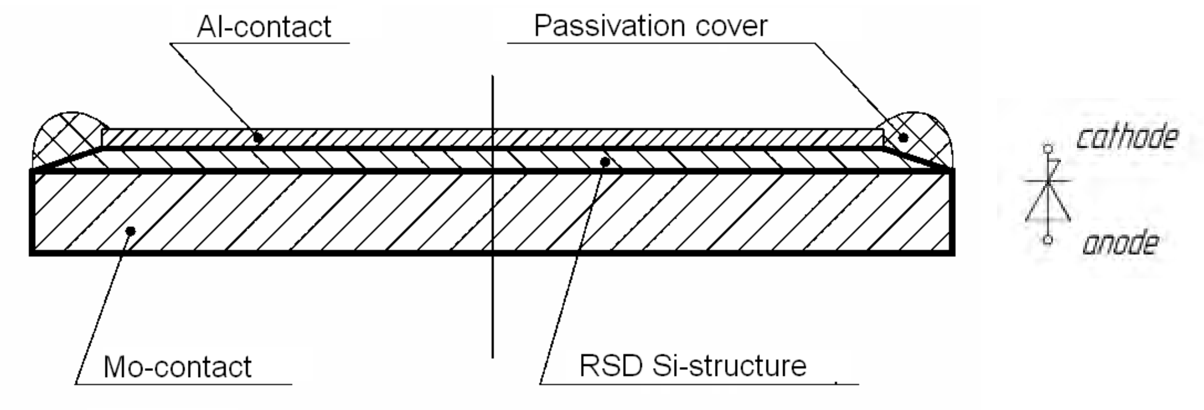


Fig. 1a. Reverse-switched dynistor without case (for variant "1")

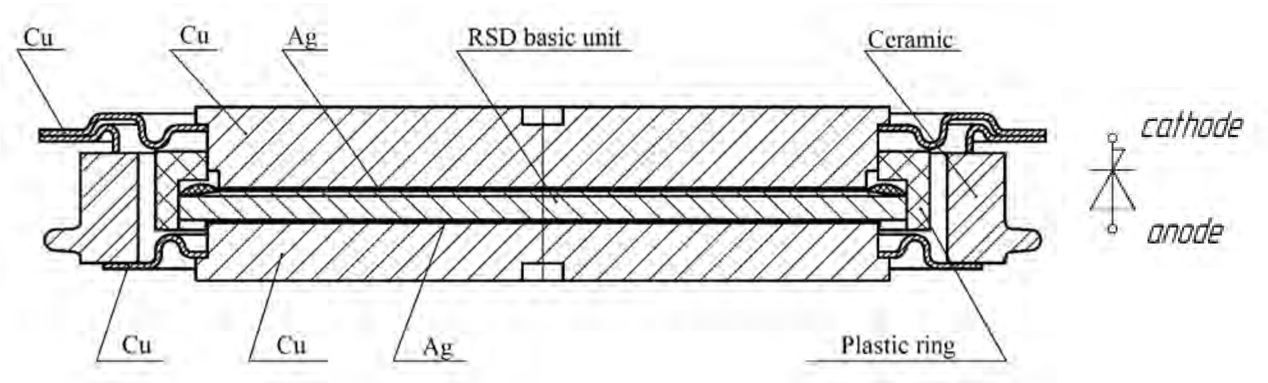


Fig. 1b. Reverse-switched dynistor in metal-ceramic press pack case (for variant "2")

1.3.2 Fig. 2 presents design example of high voltage RSD-DS, design variant 1, for commutation of high current pulses in energy storage devices, for indoor operation by temperature +10 - +35°C and relative humidity up to 80% (T = 25°C).

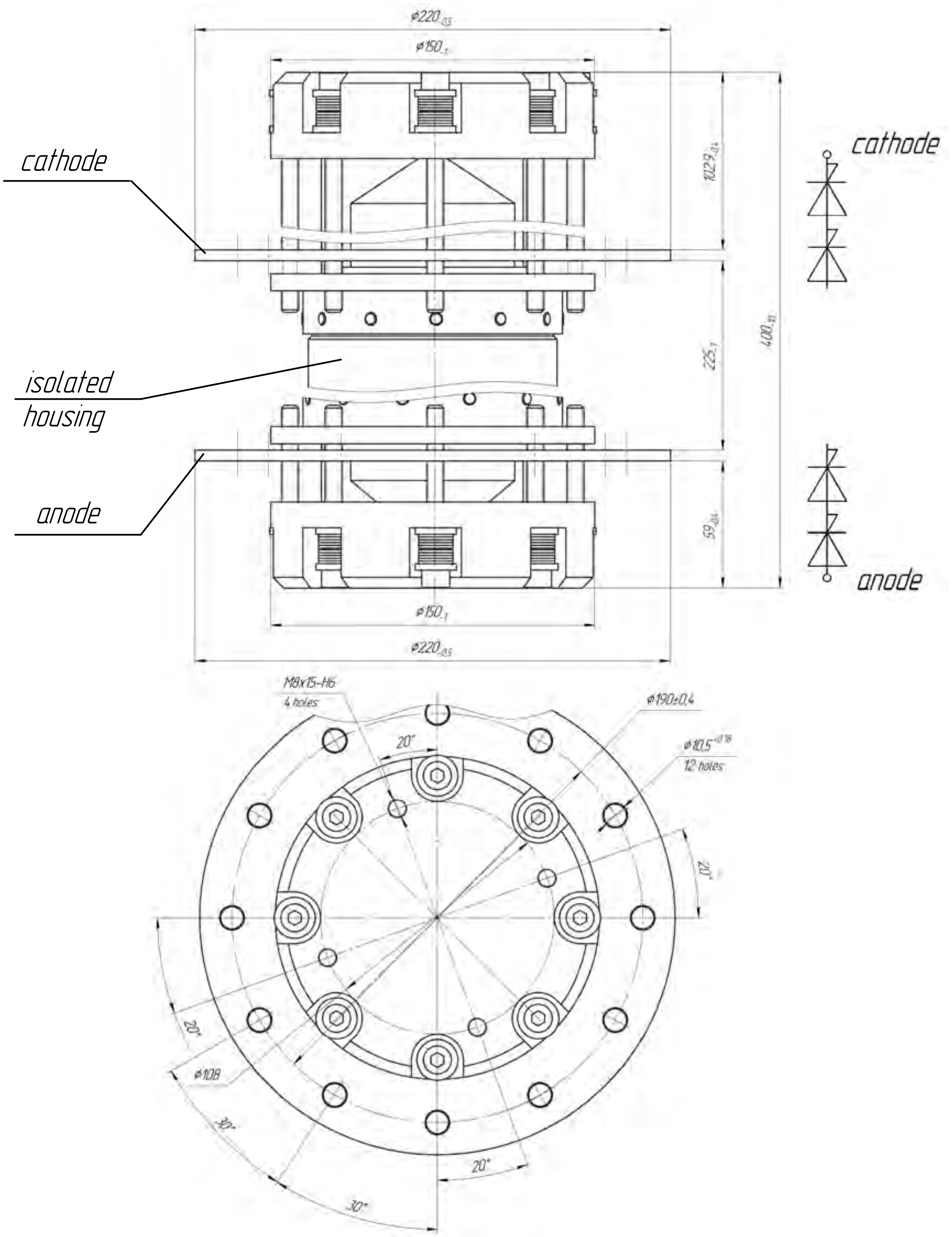


Fig. 2. RSD-based pulse current commutator up to 300 kA (design variant 1)

Commutator includes RSD basic units in series connection (Fig. 1a) that are selected according to electrical parameters for operation without shunt resistors. RSD number depends on commutator operation voltage.

1.3.3 Fig. 3 presents high voltage RSD-DS design example of design variant 2, for commutation of high current pulses in energy storage devices, for indoor and outdoor operation by temperature from -40°C up to +50°C and relative humidity up to 98% (T = 40°C).

RSD-DS design variant 2 is analogous to standard high voltage stack design type BipSTACK with press-pack power semiconductor devices connected in series (Fig.1b) and heatsinks (by necessity). Each commutator design and device types are selected in accordance with Customer required operation mode.

Options: smoothing resistors, RC-circuits, varistors, trigger block.

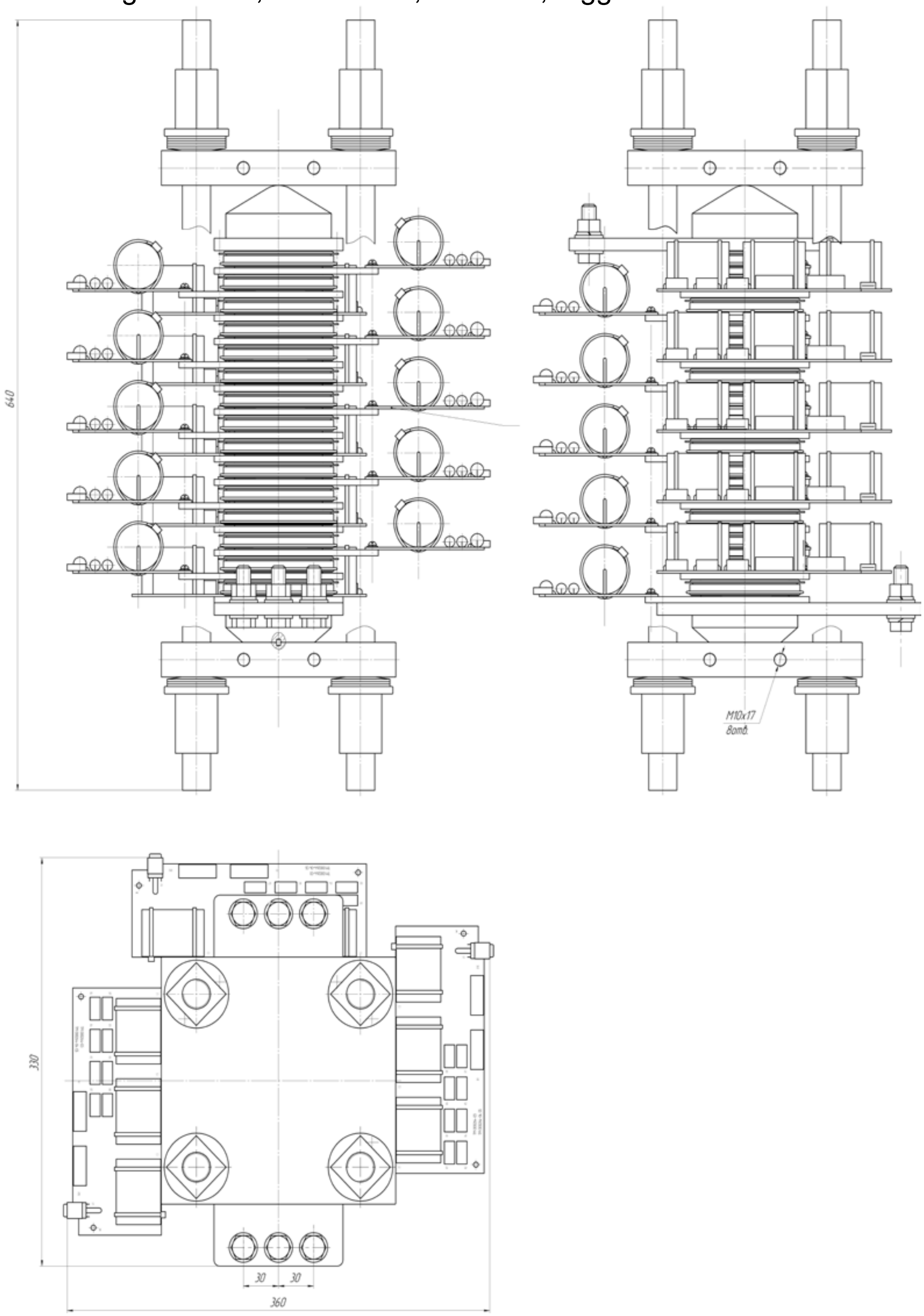


Fig. 3. RSD-DS design for pulse current up to 300 kA (design variant 2)

1.4 RSD silicon structure

Reverse-switched dynistor is two-terminal reverse conducted thyristor with integrated antiparallel diode (fig. 4). Thyristor and diode sections are integrated in the same silicon structure. Layout is optimum to minimize dynistor turn-on time and power losses in pumping and commutation mode.

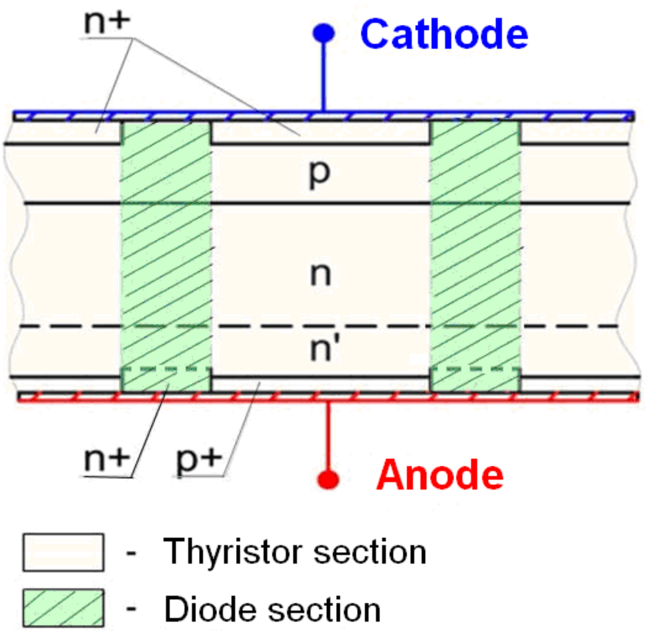


Fig.4. RSD silicon structure

1.5 RSD equivalent circuit and operation principle

Fig. 5 presents symbol and equivalent circuit of RSD.

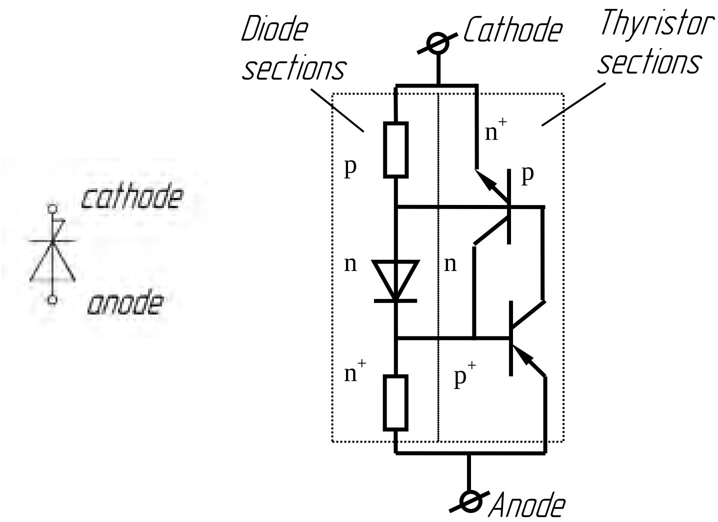


Fig.5. RSD symbol and equivalent circuit

Fig.5 explains RSD turn-on process.

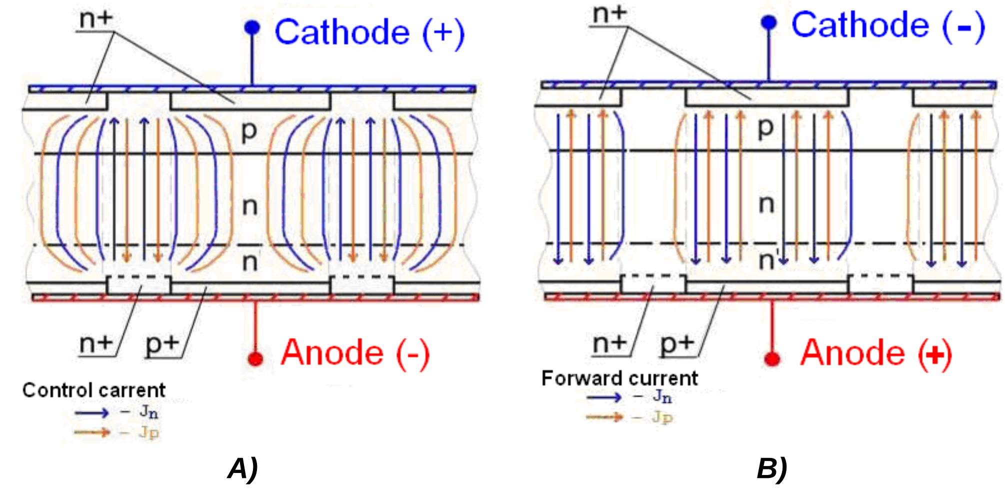


Fig.5. RSD operation modes:
A) Carrier storage B) On-state condition

RSD is triggered by means of short control current pulse under reverse voltage applied (carrier storage mode). RSD layout is so that control current flows through diode sections in axial direction homogeneous over whole structure surface. This current leads to carrier injection from both emitter junctions into base regions and triggers the regenerative process of RSD turn-on. RSD turns-on homogeneous over whole structure surface in very short time, like diode. Integrated antiparallel diode can be used also as damping diode by fault mode in discharge circuit (for example, cable breakdown), that can lead to current oscillations.

2 RSD specification and characteristics

2.1 RSD I-V characteristic

RSD forward off state characteristic is analogous to thyristor off state characteristic, and RSD reverse characteristic is analogous to diode on state characteristic (fig. 6)

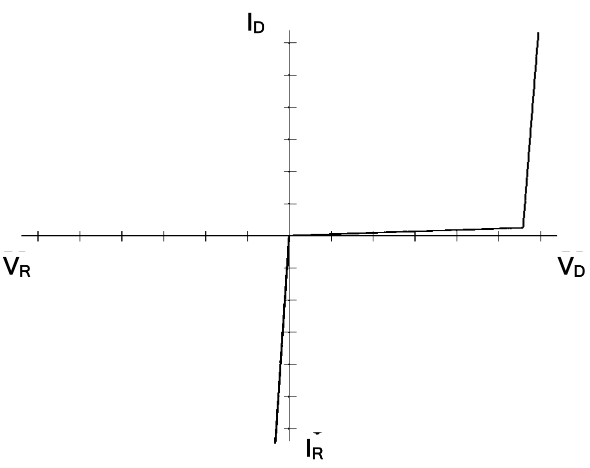


Fig. 6. RSD forward and reverse current-voltage characteristics

2.2 Typical RSD operation circuit

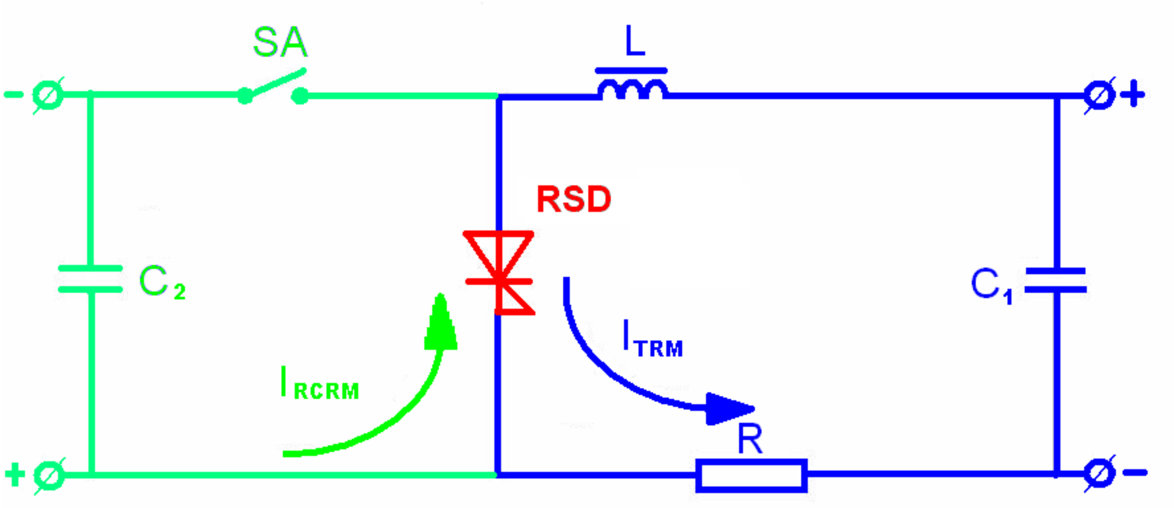


Fig. 8 RSD circuit diagram

Power section (thick) includes following components:
- condenser battery of big capacity C_1;
- load resistor R;
- reverse-switched dynistor RSD;
- delay coil L (magnet saturation device)

Control circuit includes:

- condenser C_2 (1…5 μF)
- switch SA (semiconductor device, vacuum or gas-discharger)

Condensers C_1 and C_2 should be first charged for current commutation. After that, the switch SA is closed and short (1…3 μs) current pulse I_{RCRM} flows through DSD in reverse direction. This current is RSD control current. Choke L locks power circuit from control current (choke delay time is ≈ 3μs).

2.3 RSD parameter and characteristic designation

Fig. 9 shows current and voltage waves during RSD turn-on.

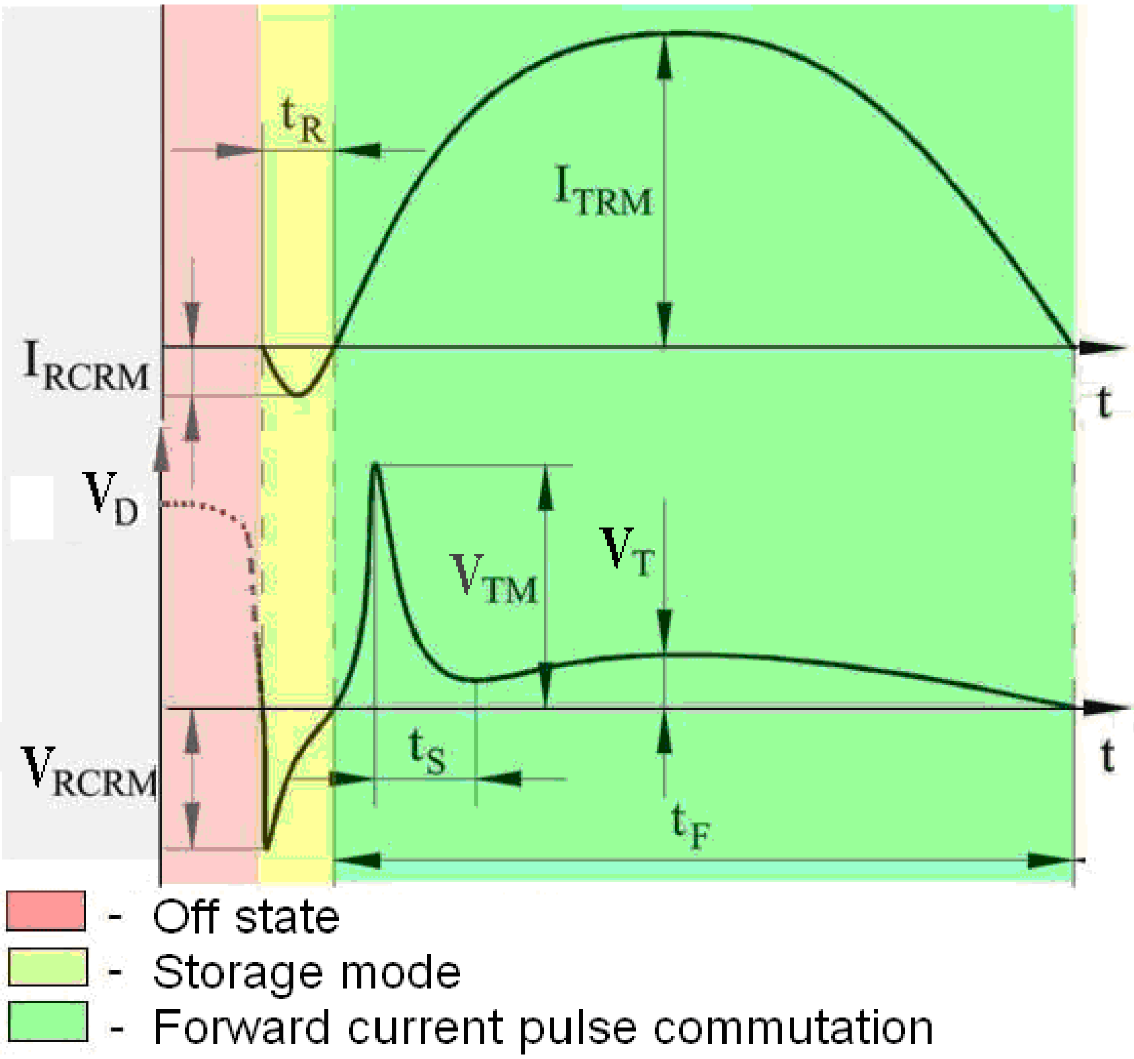


Fig. 9. Current and voltage waves during turn-on

Basic parameter and characteristic designations:

V_D – forward blocking voltage, applied to RSD before turn-on
I_{RCRM} – control current pulse magnitude
V_{RCRM} – voltage drop during control current flow
t_R – control current pulse duration
I_{TRM} – on-state current magnitude
t_F – on-state current pulse duration
t_{TRM} – forward current pulse duration
V_{TM} – commutation spike voltage drop magnitude
t_S – commutation spike voltage duration
V_T – on-state voltage drop

All connected in series RSDs in stack are triggered from single trigger generator that is connected in parallel to commutator (see Fig. 8). Trigger current from generator flows through all connected in series RSDs. This trigger method has another one advantage prefer to thyristor commutators – effectiveness and reliability of trigger circuit is much more higher.

Fig.10. RSD commutator 300 kA, 25 kV DC with control generator

Fig. 10 presented trigger pulse generator can form pulse current up to 10 kA, 3÷5 μs duration.

2.4 Basic parameters of RSD-DS commutators

Type	Chip diameter	V_{DC}	I_{TRM}	I^2t	I_{RCRM}	$(di/dt)_{cr}$	$(dv/dt)_{cr}$	n*	T**		
			t_p=500 µs		t_p=1-2 µs			$I=I_{TRM}$	I_{TRM}	0,6 I_{TRM}	0,4 I_{TRM}
	mm	kV	kA	A^2s10^6	kA	kA/µs	V/µs	pulse	minute		
KRD-50-25	40	20-25	50	0,63	0,6	100	1000	10^4	10	1	0,5
KRD-80-25	50	20-25	80	1,6	1,0	100	1000	10^4	10	1	0,5
KRD-100-25	56	20-25	100	2,5	1,5	100	1000	10^4	10	1	0,5
KRD-125-25	63	20-25	125	3,9	2,0	100	1000	10^4	10	1	0,5
KRD-250-25	76	20-25	250	15,6	3,5	100	1000	10^4	10	1	0,5
KRD-320-25	90	20-25	320	25,6	4,5	100	1000	10^4	10	1	0,5
KRD-400-25	100	20-25	400	40	5,5	100	1000	10^4	10	1	0,5

** $n = 10^5$ by $I=0,6\ I_{TRM}$; $n = 10^6$ by $I=0,4\ I_{TRM}$*
*** T - period of pulse repetition*

KEY FEATURES

- ♦ Two-electrode discharge switches on the base of reverse switched dynistors (RSD)
- ♦ Reverse-injection triggering
- ♦ Fast and homogeneous (like diode) turn-on with low switching losses
- ♦ High effectiveness and reliability by commutation of short current pulses with duration from few up to some hundreds microseconds with very high di/dt
- ♦ Triggering possibility of one or some connected in series or in parallel switches by means of single control block

3 Commutator selection for single pulse operation

Presented in Table 1 discharge current magnitudes are valuable only for pulse duration 500 µs. For applications in different modes are to use calculated dates below. Fig. 11 presents calculated dependency curves of maximum permissible values of current integral (Joule integral) on pulse current magnitude for RSD-DS with different RSD structure diameters. Curve 1 corresponds to 100 mm RSD, curve 2 – 90 mm RSD, curve 3 – 80 mm RSD, curve 4 – 63 mm RSD, curve 5 – 56 mm RSD, curve 6 – 50 mm RSD, curve 7 – 40 mm, correspondingly.

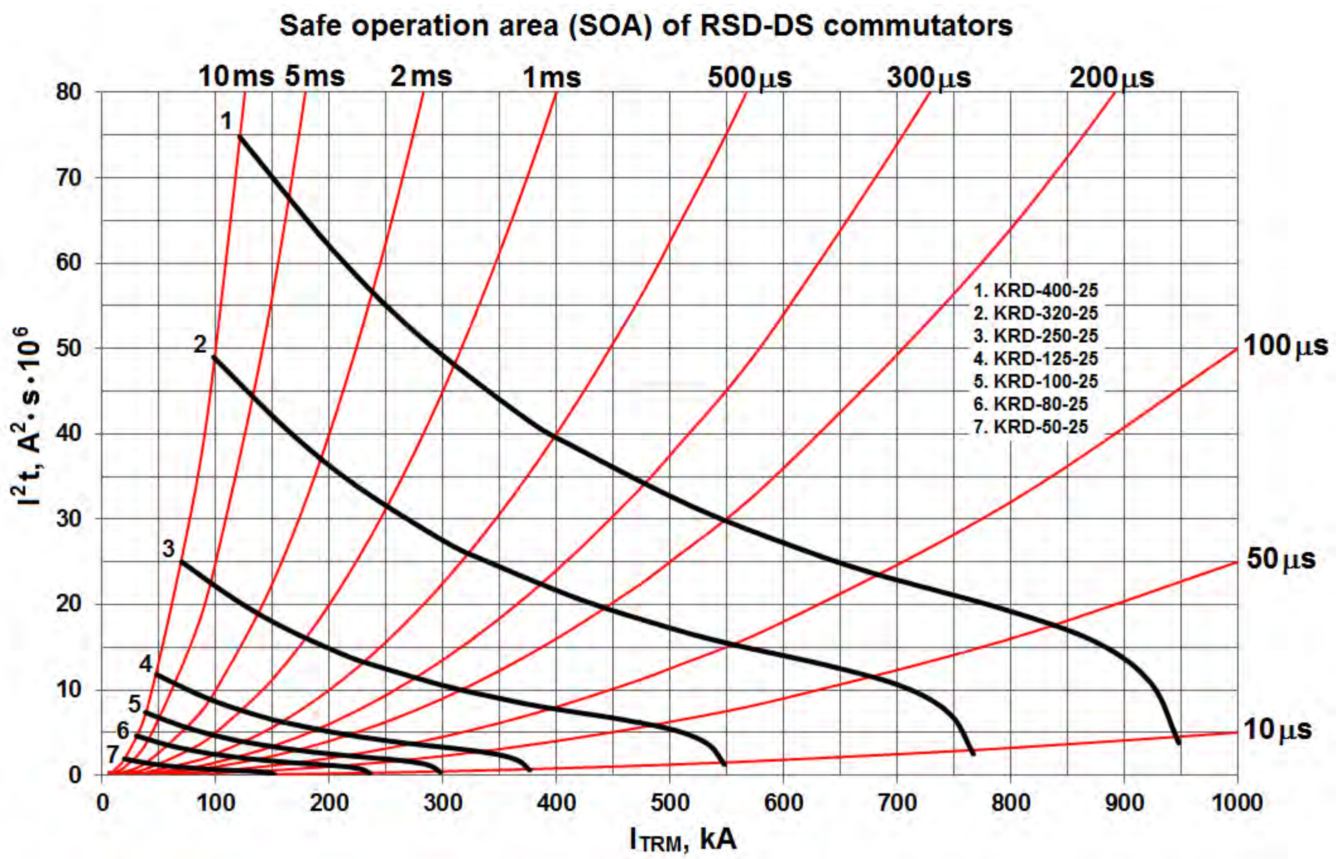


Fig. 11. Safe operation area (SOA) of RSD-DS commutators.

All presented curves are isotherms. Each point of the curve corresponds to condition T_{jmax} = const, where T_{jmax} is maximum permissible junction temperature during single current pulse commutation. For RSD it is approximately 250°C.

Each RSD-DS commutator SOA lays below its isotherm.. Presented on the Fig. 11 dependencies allow KRD selecting as discharge switch for single pulse operation in current range from 20 up to 950 kA with pulse duration from 10 µs up to 1 ms.

TYPICAL APPLICATIONS

♦ Pulse power engineering and high power electronics
♦ Condenser batteries with large stored energy
♦ Supply systems of power lasers and electromagnets
♦ Industry equipment for electro-pulse technologies
♦ Switches in microsecond and sub-millisecond ranges

4 Application examples of RSD-DS in pulse systems

RSD (quantity)	Chip dia-meter, mm	Commutator (quantity)	Parameters of storage and commutation system					Equipment	Develop-ment and supply year	Reference
			C, μF	V, kV	E, MJ	I, kA	t_p, ms			
RSD163 (270)	63	KRD-100-25 (18)	17820	20-24	5,13	1300	0,5	Condenser battery of laser system «Luch»	2001	[1]
RSD163 (15)	63	KRD-100-25 (1)	900	20	0,18	60	0,5	Electromagnet supply system	2004	
RSD153 (80)	50	KRD-70-18 (8)	3200	18	0,5	400	0,15	Capacitive storage device module	2007	[2]
RSD163 (30)	63	KRD-100-25 (2)	1800	20	0,36	130	0,5	Electromagnet supply system	2009	
RSD373 (400)	76	KRD1-250-25 (27)	290	24	0,835	250	0,5	Capacitive storage device module of power laser	2015-2016	
RSD163 (15)	63	KRD-100-25 (1)	640	24	0,184	42	0,7	Laser system	2016	
RSD163 (75)	63	KRD-100-25 (5)	640	24	0,184	42	0,7	Laser system	2017	
RSD373 (190)	76	KRD1-250-25 (12)	290	24	0,835	250	0,5	Capacitive storage device module of power laser	2017	

5 References

[1] N.N.Beznasyuk, I.V.Galakhov, S.G.Garanin et al. «The four-channel laser facility LUCH – a module of the ISKRA-6 facility» // Proceeding of XXVII European Conference on Laser Interaction with Matter ECLIM-2002 (2002).

[2] B. E. Fridman, R.S. Enikeev et al. «A 0,5-MJ 18-kV Module of Capacitive Energy Storage» // IEEE Transactions on Plasma Science, Vol.30, No.2, February 2011, pp. 769-774.