JOINT-STOCK COMPANY
«ELECTROVIPRYAMITEL»
www.elvpr.ru

Power semiconductor devices for pulse applications

I. REVERSE-SWITCHED DYNISTORS

(Application notes)

Saransk - 2008

Contents Page

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, because of slow on-state spreading from gate into main cathode region.

Thyristor pulse operation can be improved by means of interdigitated gate structure, but this leads to essential losses of active area (up to 50-80%). Reverse-switched dynistors are most effective devices for pulse current commutation up to 500 kA and more in microsecond and submicrosecond duration range

1.2. Type designation

1.2.1. Designation example of reverse-switched dynistor for single pulse commutation

RSD173 - 300 - 20

- Voltage class (V_{DRM}/100) (**20** - V_{DRM} = 2000 V)
- Pulse operation current (I_{pw}), kA (**300** - I_{PW} = 300 kA)
- Case design number (**3** - press pack design)
- Case number (**7** - case diameter 110 ± 5 mm)
- Design index number for given case number
- Device type (**RSD** - reverse-switched dynistor)

1.2.2. Designation example of RSD-based high voltage commutator for single pulse operation

KRD - 25 - 300

- **300** — Commutated pulse current (I_{pw}), kA (**300** - I_{PW} = 300 kA)
- **25** — operation voltage, kV (**25** - V_D = 25 kV, DC)
- **KRD** — Commutator type (**KRD -** RSD-based commutator)

1.3 RSD-based switch design

1.3.1. Reverse-switched dynistor design

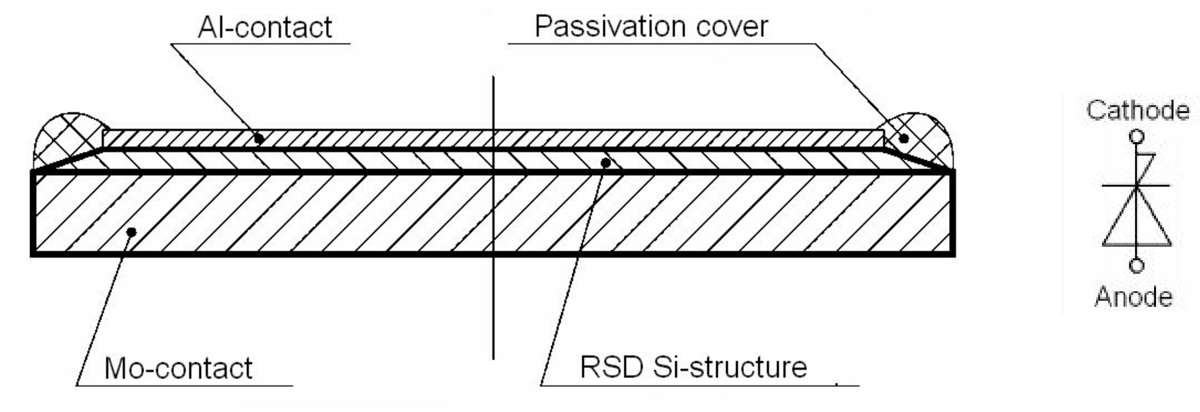


Fig. 1a. Reverse-switched dynistor without case

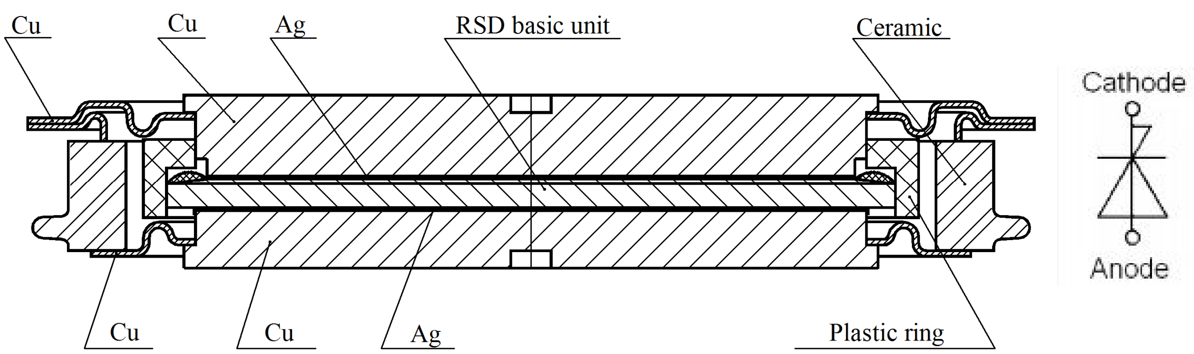


Fig. 1b. Reverse-switched dynistor in metal-ceramic press pack case

1.3.2. Design example of RSD-based high voltage switch for current commutation in unipolar single pulse generators.

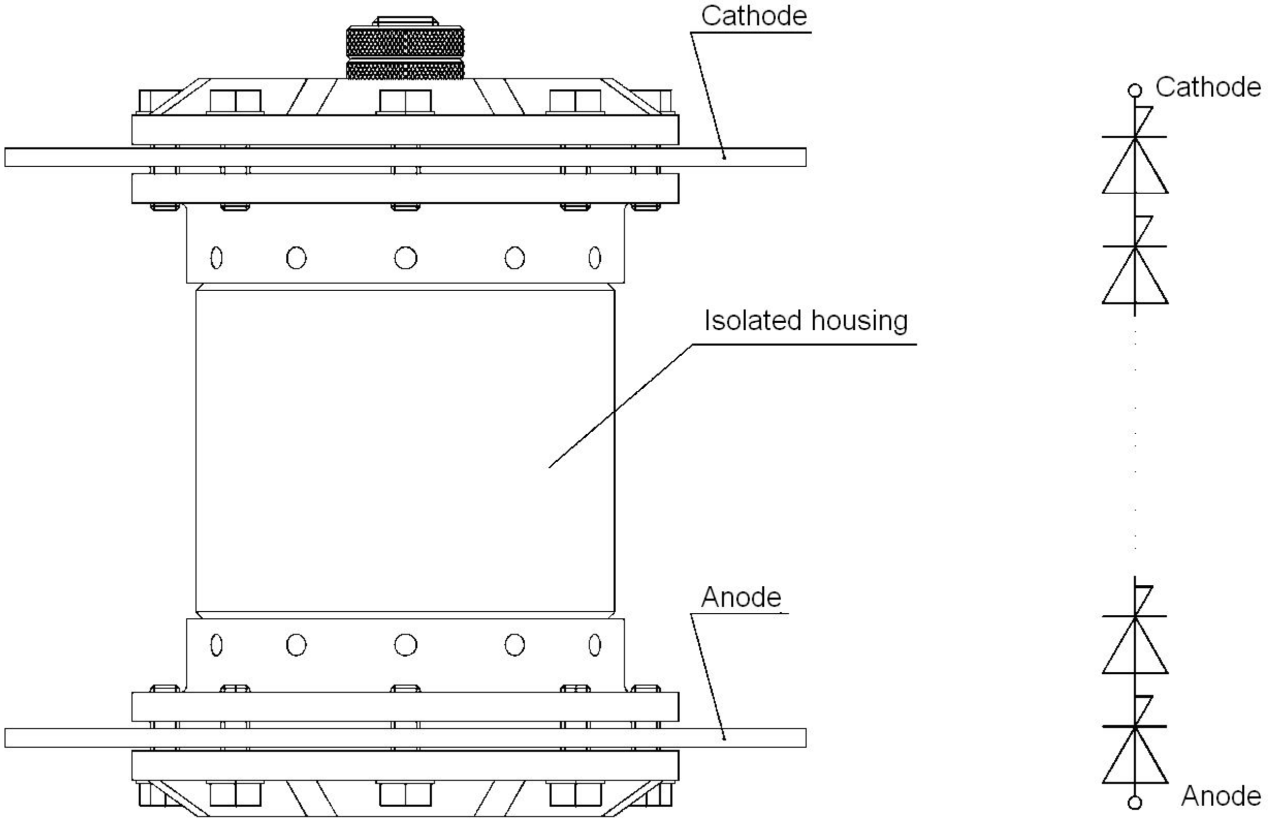


Fig. 2. RSD-based pulse current commutator 100 - 500 kA

Commutator includes RSD basic units in series. RSD number depends on commutator operation voltage. RSD number for operation voltage 25 kV DC is 15 units.

1.3.3. Design of high voltage RSD-based switch for frequency operation

Design of high voltage RSD-based commutator for frequency operation is analogous to standard high voltage stacks with press pack thyristors and heatsinks in series. Commutator construction, thyristor and heatsink types should be selected taking into account operation conditions.

1.4. RSD silicon structure

Reverse-switched dynistor is two-terminal reverse conducted thyristor with integrated antiparallel diode (fig. 3). Thyristor and diode sections are integrated in the same silicon structure. Layout is optimum to minimize dynistor turn-on time and power losses.

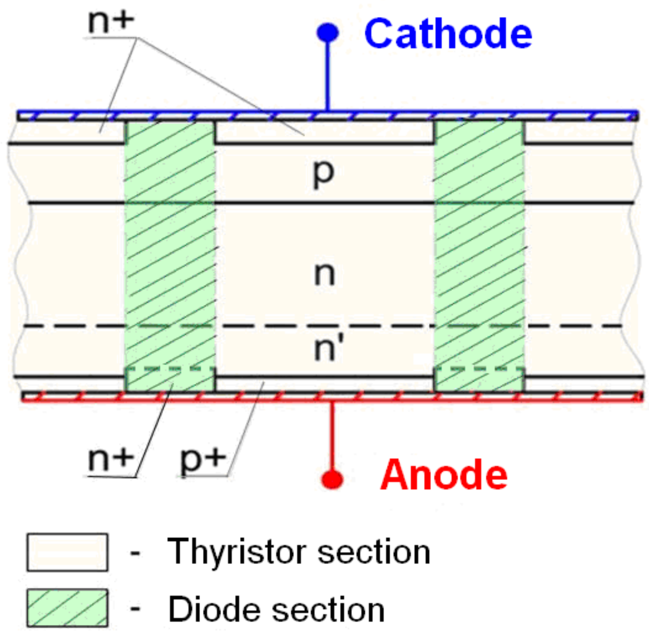


Fig.3. RSD silicon structure

1.5. RSD equivalent circuit and operation principle

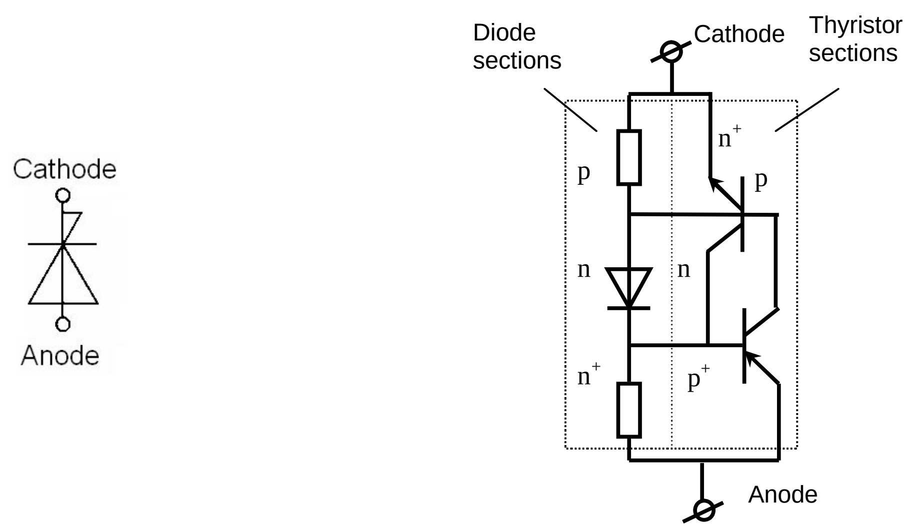
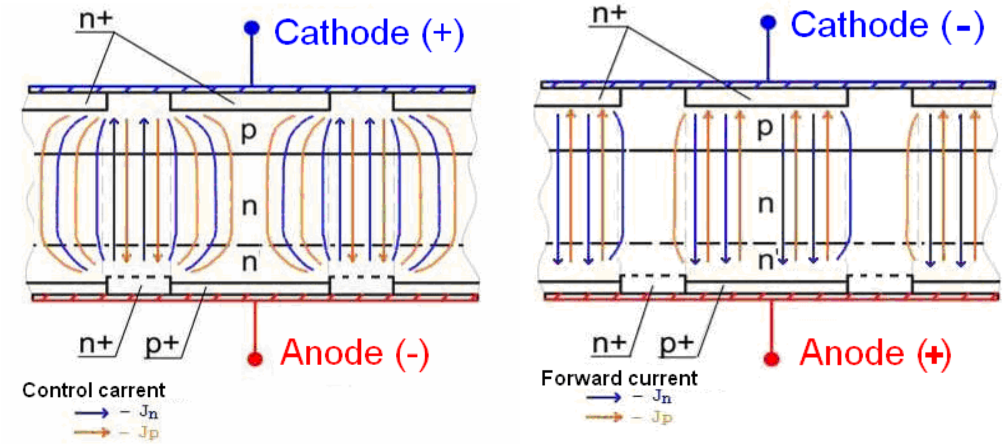


Fig.4. RSD symbol and equivalent circuit

Fig.5 explains RSD turn-on process.



A) *B)*

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 off 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 current-voltage 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)

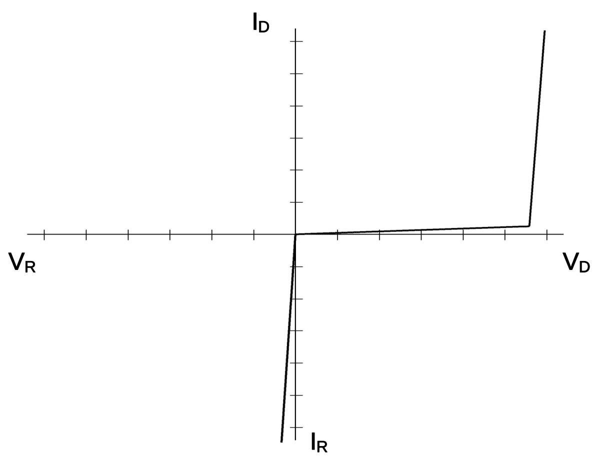


Fig. 6. RSD forward and reverse current-voltage characteristics

2.2. Typical RSD operation circuit

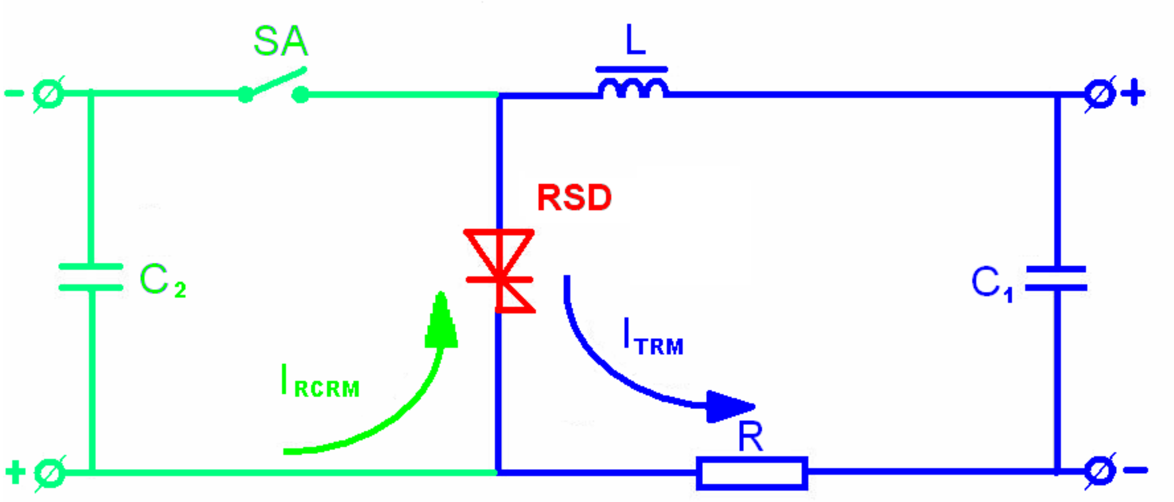


Fig. 7. RSD circuit diagram

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. 8 shows current and voltage waves during RSD turn-on.

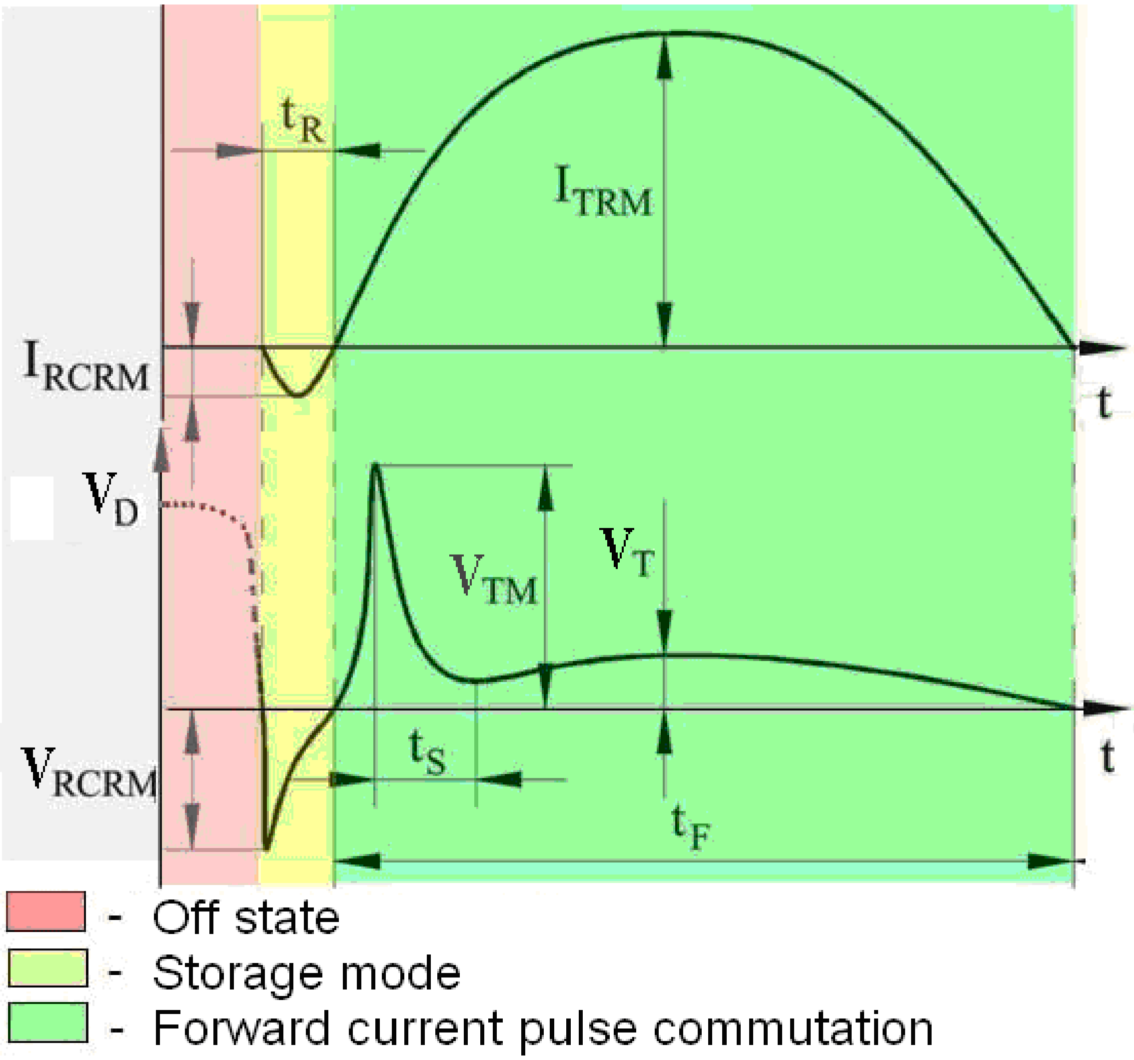


Fig. 8. Current and voltage waves during turn-on

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
V_{TM} – commutation spike voltage drop magnitude
t_S – commutation spike voltage duration
V_T – on-state voltage drop

2.4. Demands to control current pulse parameters

Control current pulse magnitude should be large enough for RSD turn-on with minimum losses that are proportional to commutation spike voltage magnitude (V_{TM}).

RSD turn-on proceeds so:

1. At the instant t = 0 device is in off-state.

2. During $0 < t < t_R$ reverse current pulse flows through RSD structure, resulting in charge Q_R storage in base regions. Q_R quantity should be much more as critical RSD turn-on charge Q_{crit}.

The total injected charge $Q_R = \int I_R(t)dt$ shall be more as excess carrier charge in base regions, since certain portion of charge compensates ionized donor and acceptor atoms in space charge region of collector junction, whose bias changes from negative to positive. Another Q_R portion recombines at time interval between 0 and t_R. Q_R can be controlled through control current pulse magnitude I_{RCRM}.

3. Forward voltage is at $t > t_R$ applied causing forward current I_{TRM}. Holes from collector vicinity of n-base jump over into p-base, where one portion recombines on cathode contact and another portion compensates the electron space charge injected from n^+-emitter. Electrons from n-base flow simultaneously through n^+-shorts to anode contact, causing holes injection from p^+-emitter. When current rises not too rapidly and stored charge density is large enough, injected into p-base electrons will come to collector junction earlier than collector vicinity will be depleted. After that collector vicinity cannot be depleted and collector bias remains positive.

Forward spike voltage V_{TM} depends mainly on base regions conductivity. When $Q_R >> Q_{crit}$, RSD commutate current pulses of large magnitude without current filaments (fig. 9, curve 1).

The different situation arises by stored charge shortage or by very fast forward current rise, when excess carrier density in collector vicinity becomes equal zero earlier than injected from cathode emitter electrons pass the p-base.

Space charge region of collector junction is by them expanded, collector is reverse biased and anode current is limited. It results in large commutation spike voltage and rise of fall time (fig. 9, curve 2). It can lead to sharp losses rise, overheating and device damage. Hence for proper RSD operation current limitation from structure itself should be avoided.

Fig. 10 shows commutation spike voltage during RSD turn-on versus control current magnitude.

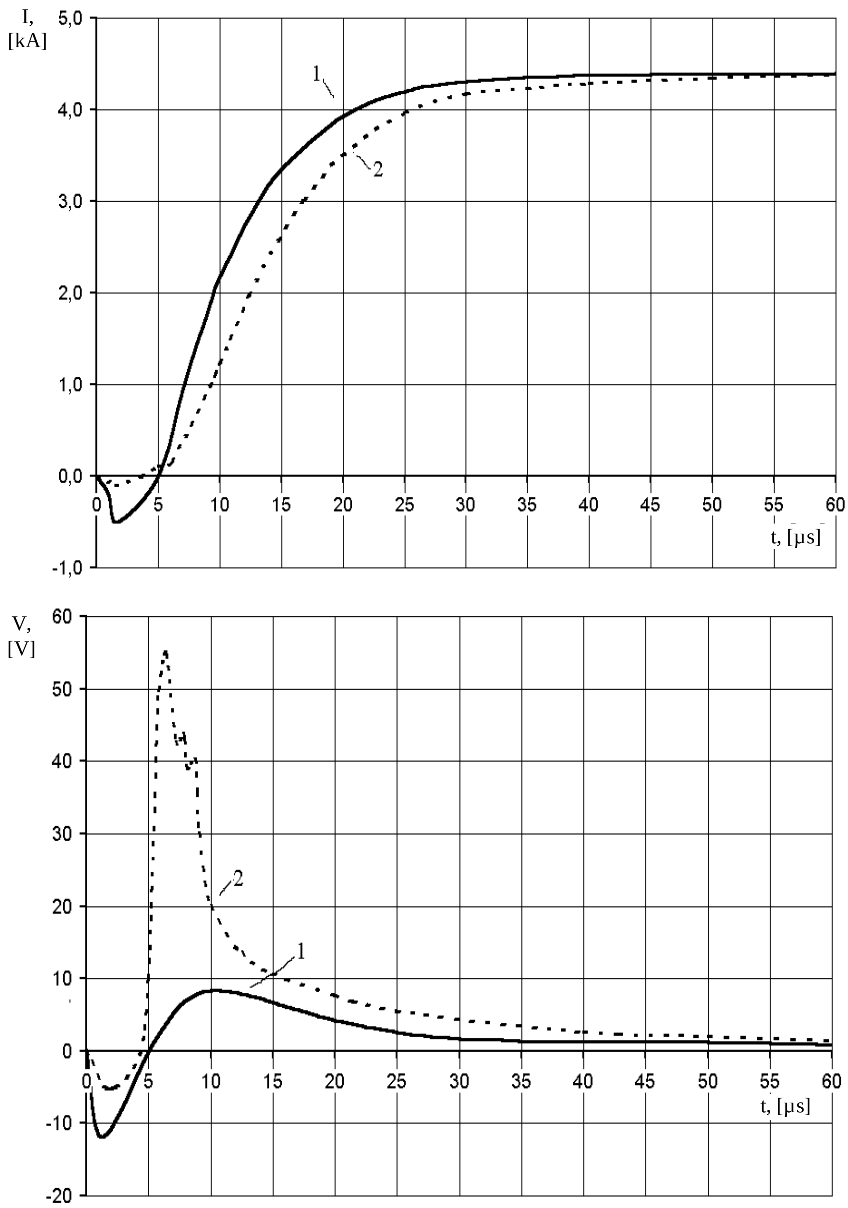


Fig. 9. Current and voltage waves across RSD for V_{DRM}=3500 V by different control current magnitudes: 1 - I_{RCRM}=500 A, 2 - I_{RCRM}=100 A.

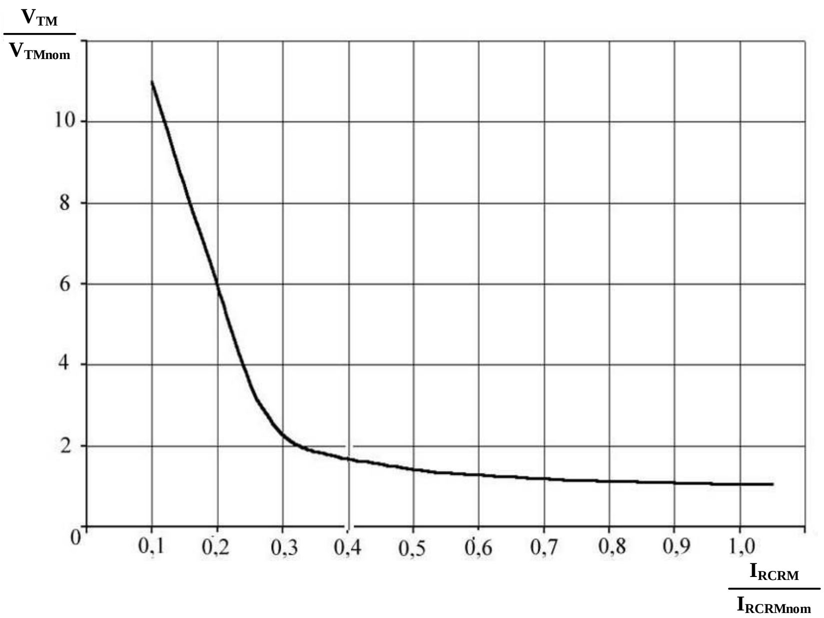


Fig. 10. Commutation spike voltage versus control current magnitude

Rated control current $I_{RCRMnom}$ values for fast and full RSD turn-on with minimum switching losses are 1.0 - 1.5 kA, pulse width 1.5 - 2.0 µs for RSD series 163, 173 and 193.

Fig. 11 shows as example current wave and voltage drop wave for RSD173-300 by I_{RCRM} = 0.7 kA, t_R = 2 µs.

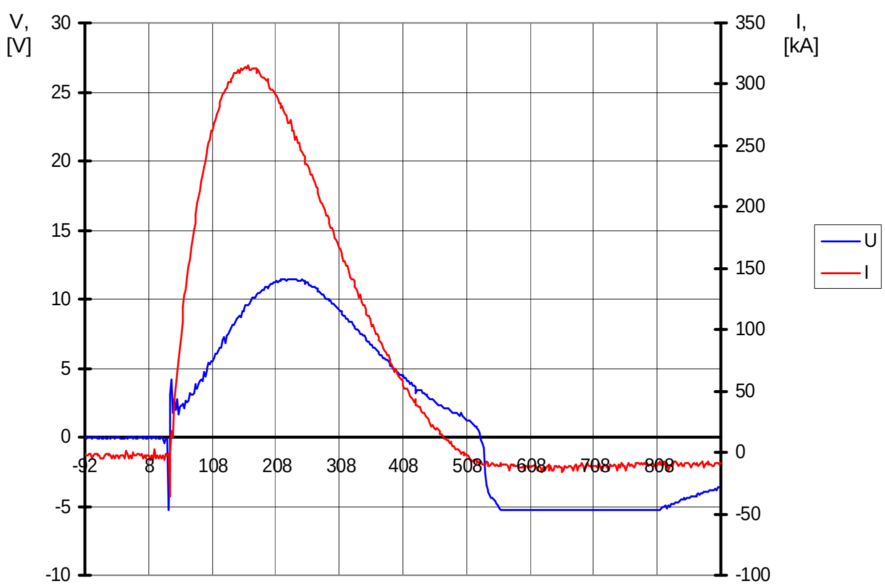


Fig 11. Pulse current commutation 320 kA, 450 µs.
Maximum voltage drop on RSD is 12V.

RSD basic units connected in series in high voltage stack are controlled with single control current generator connected in parallel to commutator (fig. 12). Control current from pulse generator flows through all RSD in series simultaneously. This switching method has advantage in comparison with thyristor commutation - sufficiently higher control reliability.

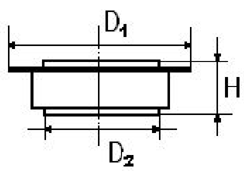
Fig.12. RSD commutator 300 kA, 25 kV DC
with control generator

Fig. 12. Control pulse generator producing pulse current up to 10 kA, 3÷5 µs

2.5. Basic parameters of reverse-switched dynistors

Table 1 shows RSD basic parameters

Table 1

Device types			RSD 143-80	RSD 153-120	RSD 253-150	RSD 163-200	RSD 173-300	RSD 183-400	RSD 193-500	
Item	Parameter	Designation	Parameter values							Notes
1	DC blocking voltage, V	V_{DC}	2000	000	2000	2000	2000	2000	2000	T_j = 0...45˚C
2	Commutated pulse current, minimum, kA	I_{TRM}	80	120	150	200	300	400	500	Non-repetitive single pulse t_p=400 µs
3	I^2t (Joule integral), minimum, $A^2s{\cdot}10^6$	I^2t	1,5	2,5	4	7	13	25	38	
4	Control current magnitude, A	I_{RCRM}	200	300	400	500	700	900	1000	t_p=1,5 ÷ 3 µs
5	Critical on-state current rate of rise, minimum, kA/µs	$(di/dt)_{crit}$	50	50	50	50	50	50	50	Single current pulse
6	Critical off-state voltage rate of rise, minimum, V/µs	$(du/dt)_{crit}$	1000	1000	1000	1000	1000	1000	1000	
7	Outlines, mm - basic unit diameter - device diameter - contact diameter - device height	 D_1 D_2 H	 40 62 36 14	 50 78 52 14	 56 78 52 14	 63 88 60 14	 70 102 72 14	 90 118 86 26	 101 140 100 26	

2.6. RSD choice for single pulse operation

Fig. 13 shows simulated maximum i^2t values (Joule integral) for single pulse versus current magnitude for different RSD types.

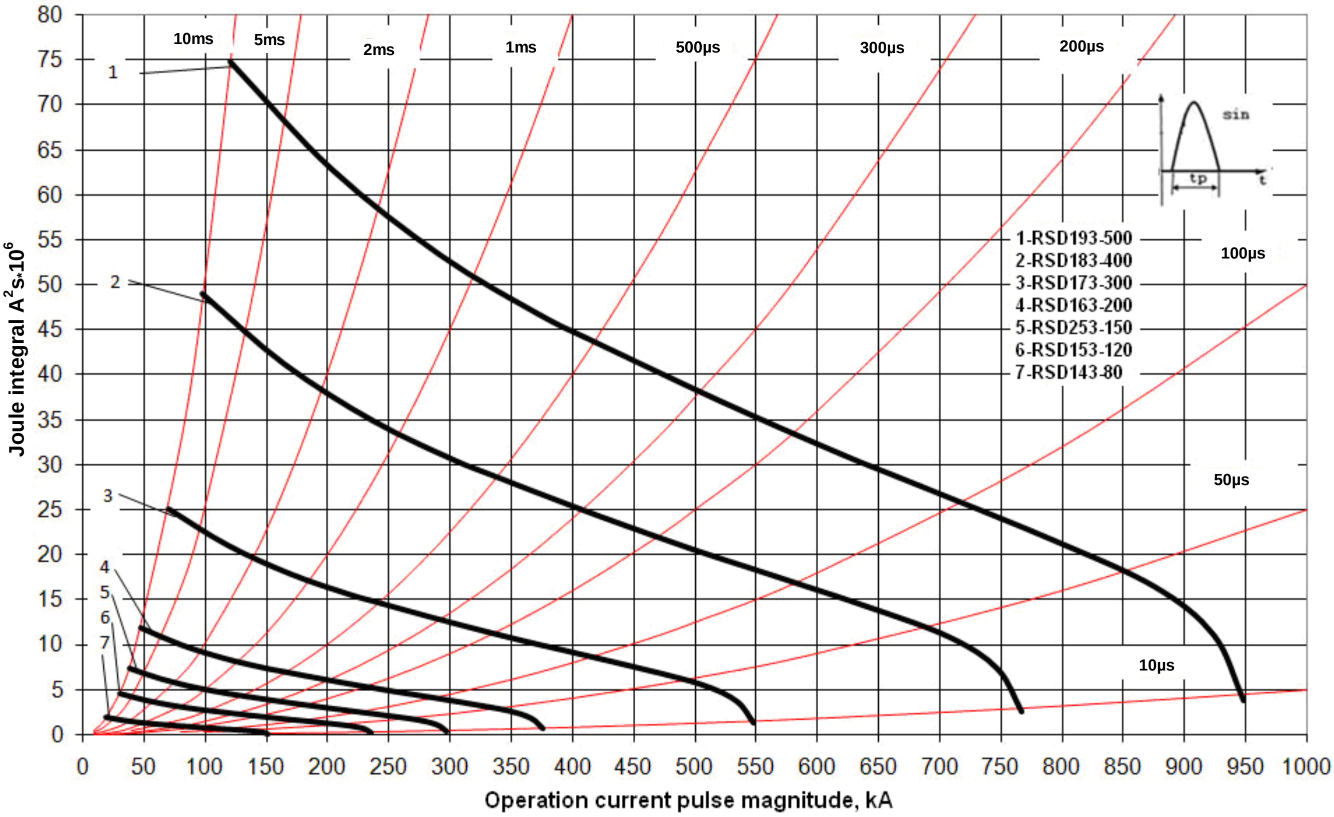


Fig. 13. RSD safe operation area (SOA) by single pulse operation

SOA curves are restricted from one side by Joule integral for single sinusoidal current pulse, and from other side by maximum rated current pulse magnitude.

By device choice for each specific operation the following parameters should be given, in accordance with current wave form:

- Joule integral ($I^2t = \int_0^{tp} i(t)^2 dt$)
- operation current pulse magnitude $I_{TRM} = I_{PW}$.

These values are used as coordinates in fig. 13, defining RSD safe operation point. The next above this point $I^2t = f(I_{TRM})$ curve determines proper RSD type and their SOA.

2.7. General

Please contact our specialists for correct RSD order and other components for pulse applications (crow bar diodes, heatsinks, high voltage stacks, drivers and so on).

JSC «ELECTROVIPRYAMITEL», Russia, Mordovia, Saransk, 430001, Proletarskaya str., 126

Phone. +7(8342) 47-04-30, Phone/Fax. +7(8342) 47-15-01,

E mail: vpruvs@moris.ru, martin@moris.ru