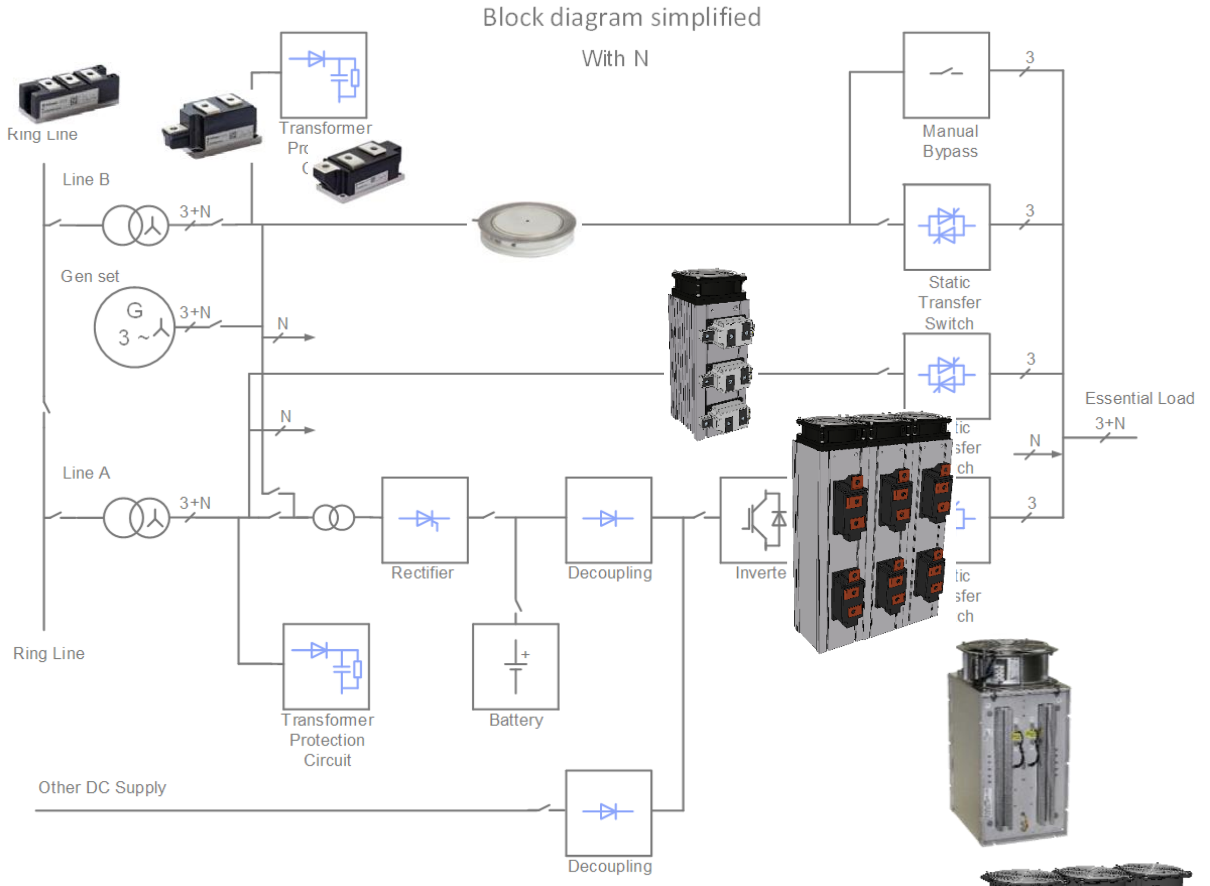
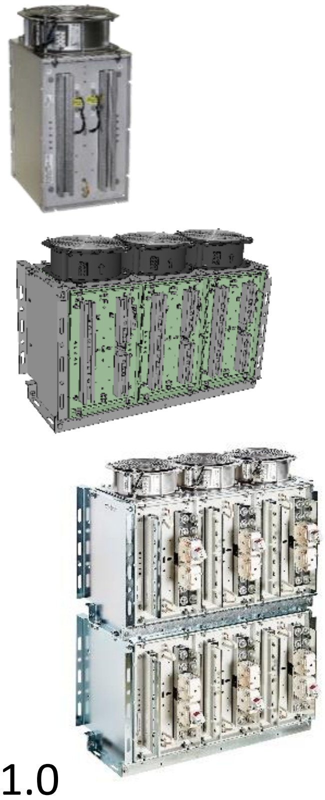
Infineon Technologies Bipolar
GmbH & Co. KG





The use of thyristors and diodes in UPS systems has a long history. The UPS application requires the use of bipolar semiconductor components today, and with great certainty, also in the future. Due to the wide voltage and power ranges, components from the complete bipolar semiconductor portfolio can be applied. The need to handle short circuits, if necessary, also requires high surge-current capability, and under certain circumstances, short-on-fail behavior for several 100 milliseconds. This document will provide an overview on bipolar semiconductors in UPS applications.

Bipolar Power Semiconductors in UPS Systems V1.0

03.05.2021

Jürgen Schiele, Adam Kwiatkowski, Nils Przybilla, Michael Stelte

Inhalt

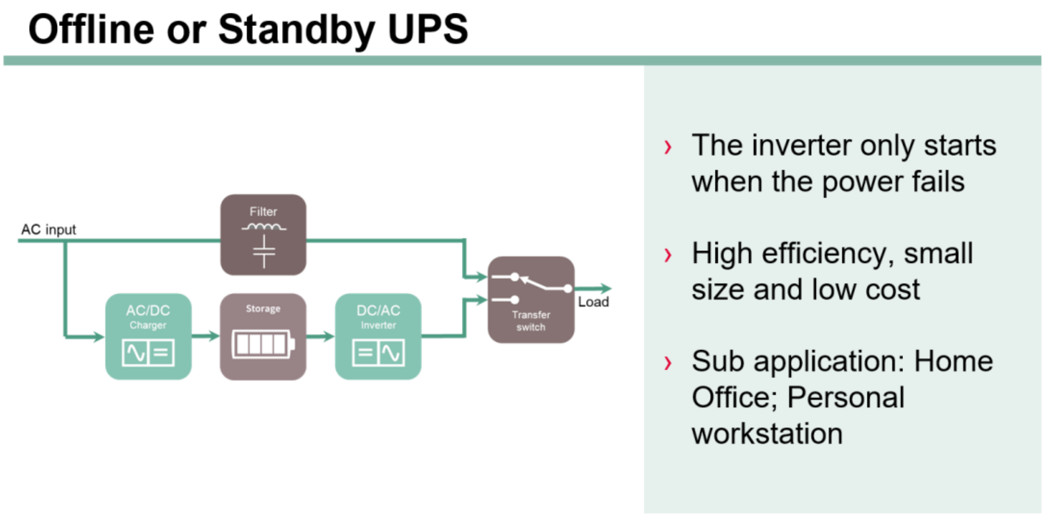
Infineon Technologies Bipolar GmbH & Co. KG

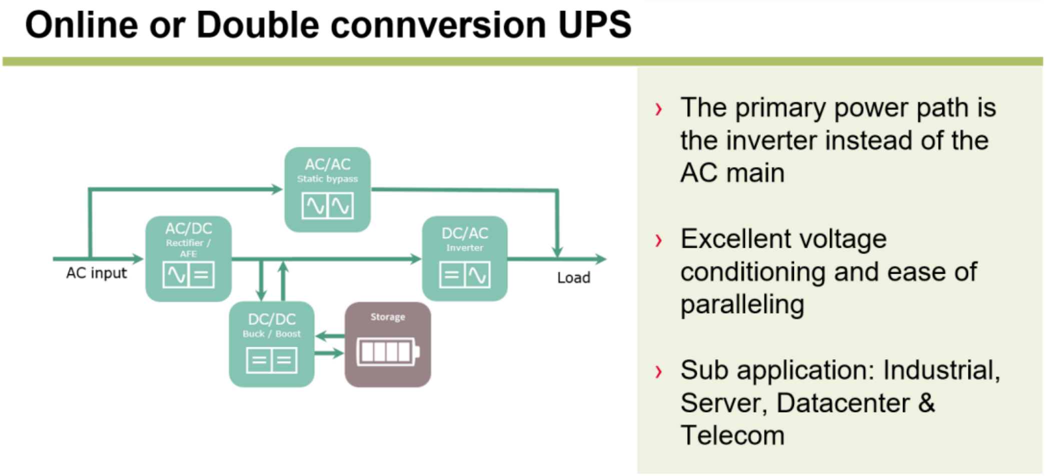
1 Abstract

The use of thyristors and diodes in UPS systems has a long history. The UPS application requires the use of bipolar semiconductor components today, and with great certainty, also in the future. Owing to the wide voltage and power ranges, components from the complete bipolar semiconductor portfolio can be applied. The need to handle short circuits, if necessary, also requires high surge-current capability, and under certain circumstances, short-on-fail behavior for several 100 milliseconds. This article describes the areas in which bipolar power semiconductors are used in a UPS system, and how they are to be designed, depending on the set-up of the UPS. Transformer protection circuits, input rectifiers, battery coupling, inverters, static bypass circuits and static transfer switches are discussed. For illustration purposes and in conclusion, fictitious-type series are presented with component suggestions. The exemplary design is based on assumed short-term overload requirements from the field. The types presented here can be used as a basis for an individual design. IGBT-based inverters are not included in the scope of this document.

2 UPS variants

The standard IEC 62040-3 (Uninterruptible power systems (UPS) – Part 3: Method of specifying the performance and test requirements) describes in detail the most important UPS concepts. [1]





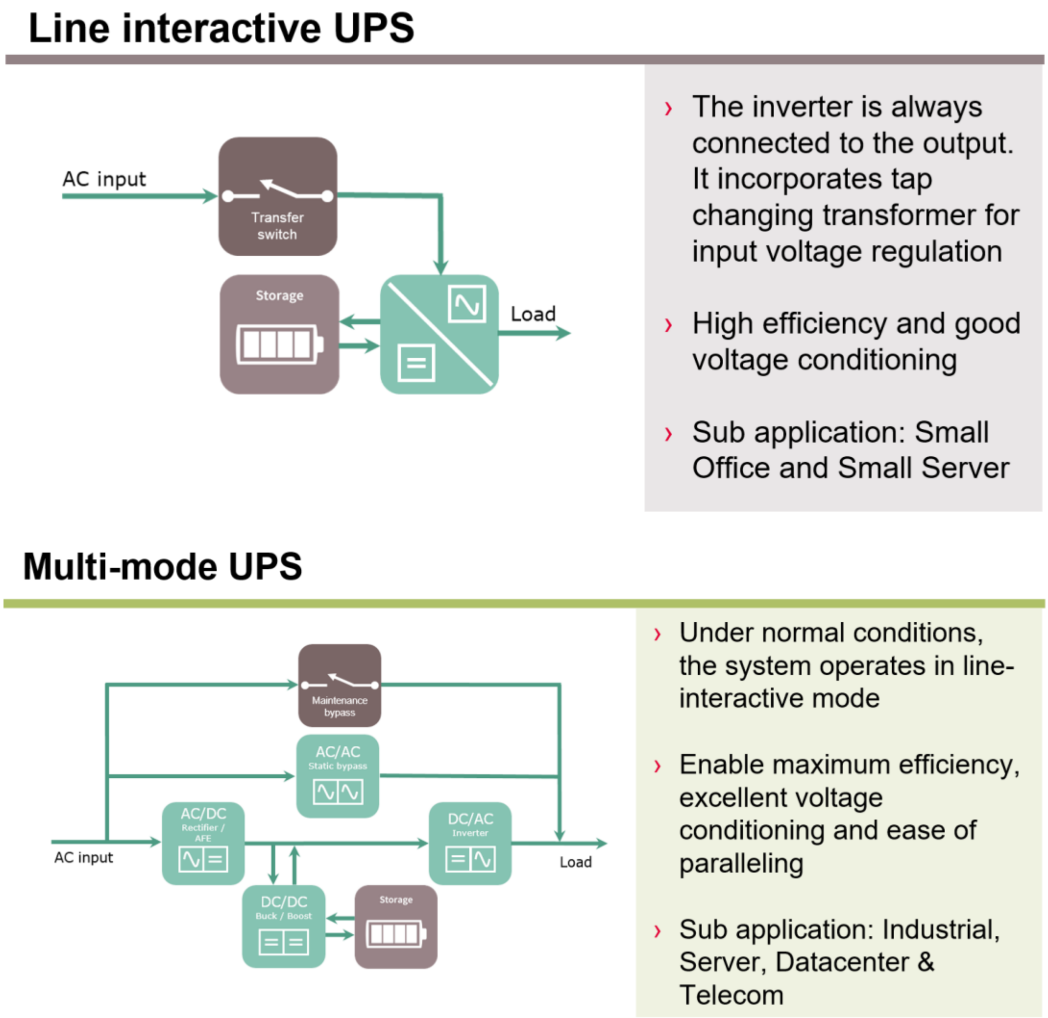


Figure 1. Types of UPS systems

The most common UPS is the online or double conversion UPS. This UPS is the basis for the following chapters. [2]

2.1 General designs

We differentiate between UPS types based on market requirements from the following fields:

- Oil & gas
- Power plants
- Heavy industry
- Standard industry
- Data center and IT
- Office (not in scope of this document)

Oil & Gas, Power Plants, Heavy industry:

DC voltage is either 108 V or 216 V due to central battery systems and standardized battery voltages. The UPS in this applications usually needs to be free of potential, therefore the use of transformers is mandatory.

A thyristor rectifier (6 or 12 pulse) feeds the system and charges the battery directly. The battery feeds the inverter. Because of the low battery voltage, transformers to grid and load couple input and output of the UPS. The battery voltage depends on the application area. The DC current level depends on the battery voltage and defines mainly the inverter power stage. For example, a 100 kVA UPS that is fed by a 108 V battery works with a DC-link current of about 1100 A. Because the UPS must provide the power also at battery's minimal voltage, the inverter must modulate the sine wave output from about 90 V DC-link voltage. According to the modulation rules, the AC output voltage of the inverter is about 73 V_{RMS} only. With that, the AC output current of the UPS inverter is 100 kVA /sqrt (3)/73 V_{RMS} = 791 A_{RMS} nominal. After the sine wave filter, the zigzag output transformer builds the N and the requested output voltage of e.g. 400 V_{RMS}. Let us say that for relatively low output power, the UPS has to work with huge internal current. The power range is from 10 to 100 kVA. The semiconductors used are modules and discs.

Standard industry:

The DC voltage is 384 V. The local battery is optimized to be charged from line voltage directly. No input transformer is required for the basic functionality. An output transformer is required to build the N. The power range is 10 to 500 kVA and more. The semiconductors used are modules and discs.

Data centers and IT:

The internal DC-link voltage is 800 V DC for systems with 400 V line voltage and 960 V DC for systems with 480 V line voltage. The UPS works internally with +-400 V DC or +-480 V DC. The center point is connected to N. With that, the required output voltage of 400 V AC or 480 V AC can be modulated directly from the DC voltage without the use of a transformer. UPS systems for data centers and IT are transformerless UPS systems. This concept reduces the footprint as well as cost. Indeed the N potential must be available for this concept.

The battery voltage is 480 V DC due to international standards. It is coupled via buck-boost converter to the internal 800 V (960 V) DC-link.

The UPS for data centers and IT comes with four inverter phases. Because zigzag output transformers do not exist, the N potential needs to be built electronically. The power range is up to some MVA. The systems are built from UPS blocks from 200 KVA to 500 kVA. With paralleling of blocks, the output capability can be scaled up to 8 MVA. Module and disc semiconductors are used.

2.2 Reasons for different design bases

Different design features are required to achieve a balance between reliability, efficiency, freedom from potential, space requirements, and cost in relation to the respective application.

Design base	Leads to:	Results in:
Battery voltage 108 V, 216 V	Fewer series-connected battery cells	Better reliability, huge footprint, higher costs
Battery voltage 384 V	Obsolete input transformer	Smaller footprint, not free of potential, less reliability
DC-link voltage 800 V	Obsolete input and output transformer -> transformerless UPS	Smaller footprint, more complex, not free of potential
Rectifier and inverter separated	Non-centralized UPS set-up; Redundancy easy to implement	Better reliability

Table 1. Design features of UPS systems and their impacts

2.3 AC and DC-link voltage level in UPS systems

The typical industrial UPS works internally with a battery-connected DC-link voltage of 108, 216 or 384 V_{avg}. The typical UPS for data centers and IT works internally with +-400 V_{avg} or +-480 V_{avg}. The typical 480 V battery is connected to the DC-link via buck-boost converter.

The AC input / output voltage levels of 230, 400, 440, 460, 480, 500, 600 or 690 V_{RMS} are adjusted with transformers if required.

Battery voltage	UPS DC-link voltage	Input transformer	Output transformer	Output voltage
108 V_{avg}	108 V_{avg}	Yes	Yes	as per transformer ratio
216 V_{avg}	216 V_{avg}	Yes	Yes	as per transformer ratio
384 V_{avg}	384 V_{avg}	No	Yes	as per transformer ratio
480 V_{avg}	e.g. +- 400 V_{avg} (800 V_{avg})	No	No	e.g. 400 V_{RMS}

Table 2. AC and DC Link Voltage levels in UPS systems

2.4 Oil & Gas UPS, Standard industrial UPS, Power Plant UPS (108, 216 V battery voltage)

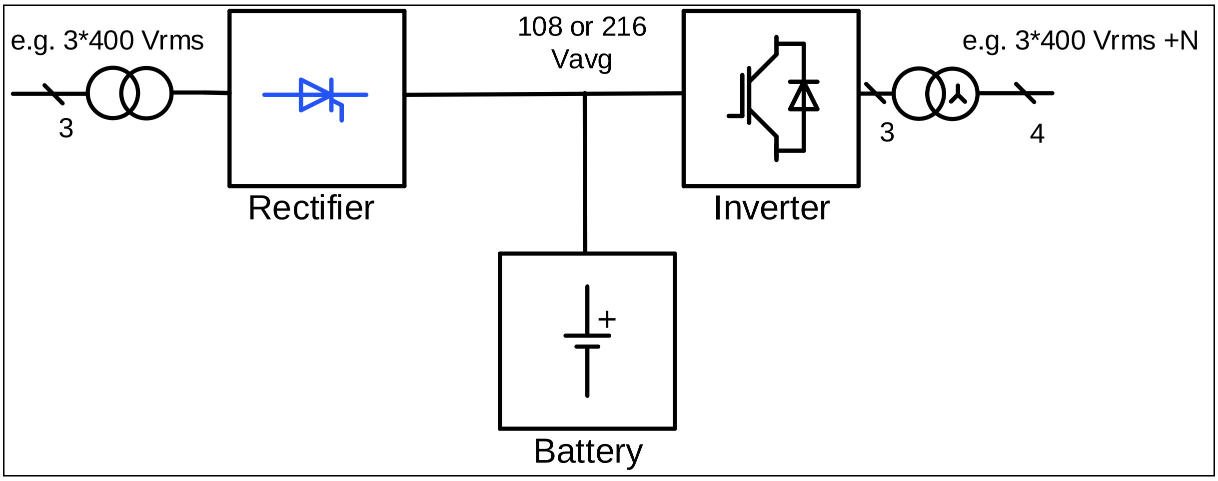


Figure 2. Standard industrial, Power Plant UPS, 108, 216 V Battery Voltage

2.5 Standard industrial UPS (384 V battery voltage)

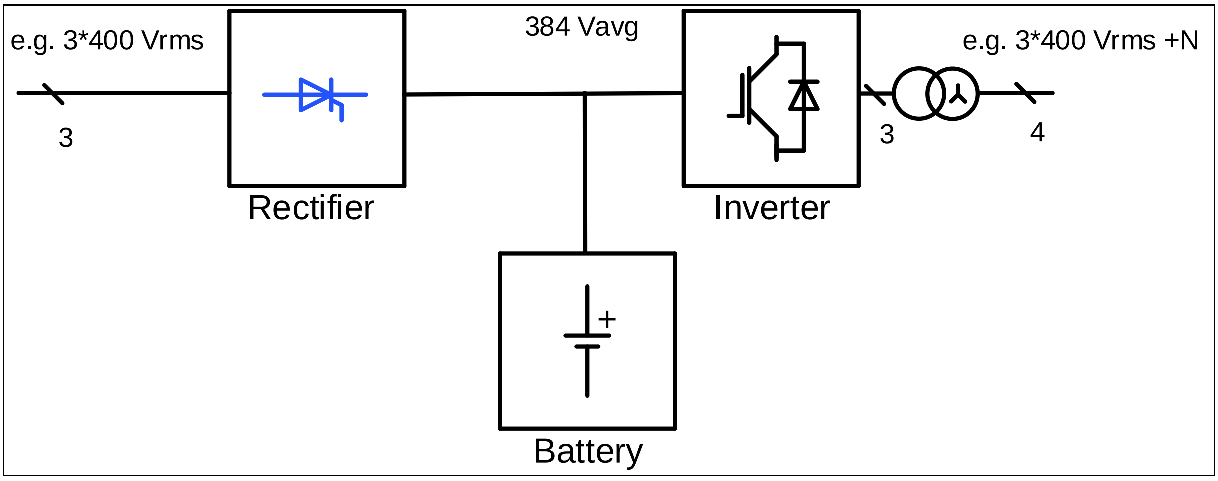


Figure 3. Standard industrial UPS, 384 V Battery voltage

2.6 UPS for data center, IT (480 V battery voltage)

UPS systems for Data centers are usually without transformers. Two voltage classes for UPS are common, line voltage 400 V_{RMS} and 480 V_{RMS}.

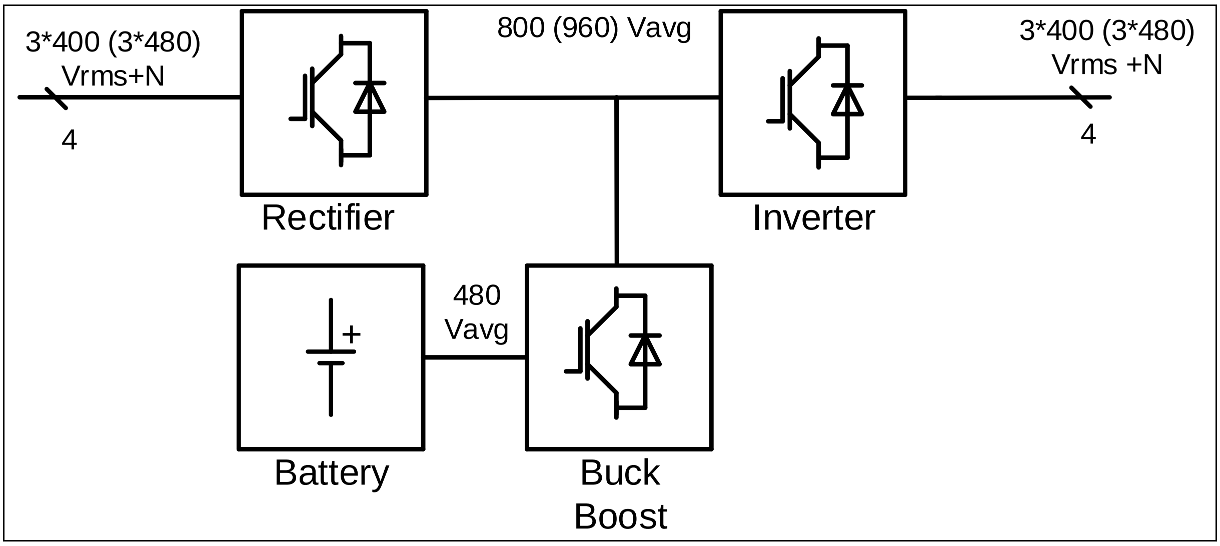


Figure 4. UPS for data centers, IT, without transformers

2.7 Power Semiconductors and Power Stacks for UPS Systems

IGBT modules are the most important power semiconductors in UPS systems. The IGBT allows PWM-controlled sine wave modulation with low effort, and assures an almost perfect line voltage for essential loads. IGBT modules are today replacing the bipolar frequency thyristors used in the past.

However, the inverter is not the only part of a UPS system that uses semiconductors. Depending on the overall concept and the requirements regarding redundancy, static bypasses and static transfer switches are installed. For these functional parts, robust bipolar semiconductors are needed.

Thyristor input rectifiers are still used in UPS systems for Oil & Gas plants and power plants, due to their robust technology.

This document deals with bipolar power semiconductors only.

2.7.1 Technology comparison for bipolar power semiconductors

The well-known semiconductor chip and device technologies provide different characteristics regarding reliability, surge-current capability and short-on-fail behavior. Depending on the application requirements, either soldered or press pack technologies need to be used. Unfortunately, the semiconductor chip and device technologies cannot be identified by the housing concept. A detailed discussion with the semiconductor manufacturer is required.

2.7.1.1 Chip technology

We differentiate between pressure-contact and solderable chip concepts. For the pressure-contact chip, the entire chip area is under electrical contact, and therefore the surge-current capability is as large as possible. In case of a failure, the pressure-contact semiconductor is shorted, which allows

the system to be turned off by fuse. The solderable chips are connected via bond wires or Cu foils. These concepts are not short-on-fail in case of malfunction, and offer less surge-current capability. Short-on-fail behavior and large surge-current capability may be mandatory for static bypass switches (SBS) and static transfer switches (STS).

2.7.1.2 Device technology

We differentiate between Press Pack discs and isolated modules. The discs offer two-sided cooling, short-on-fail behavior, and huge peak-current capability.

In modules, the chips are isolated from the baseplate and are single-side cooled. The modules can be designed with alloyed, AMPT, Solder Bond or Solder-Solder chip concepts. The alloyed and AMPT concepts are short-on-fail and offer a very large surge-current capability. The solder concepts are not short-on-fail and may have limited surge-current capability [3]. The surge current capability depends on individual design of the solder-solder concept.

2.7.1.3 Stack technology

We differentiate between modular and compact stacks. The modular stack consists of a heatsink in an isolating frame, which is prepared for the set-up different circuit configurations. Product Line: Frame Blocks and Frame Stacks. [4]

The compact stack consists of a common heatsink with a dedicated configured circuit. It is usually built from Eco Blocks, Power Blocks or Prime Blocks. Product Line: Compact Block and Compact Stack. [4] [6]

An alternative solution may be the modules primarily designed for Soft-Starter applications (e.g. sTT2000N18P55). These would make sense for high-surge current requirements regarding the continuous current (e.g. 1000% RMS current for 100 ms). Those modules are equipped with a heatsink with a large base. This design enables large, short-time currents, combined with small footprint and low costs [8].

Figure 5. Soft-starter module Power Start STT2000N18P55

2.8 Overview for a UPS system with bipolar semiconductors

Figure 6 shows a fictitious UPS system in a power plant. It consists of all important functional groups using bipolar semiconductors.

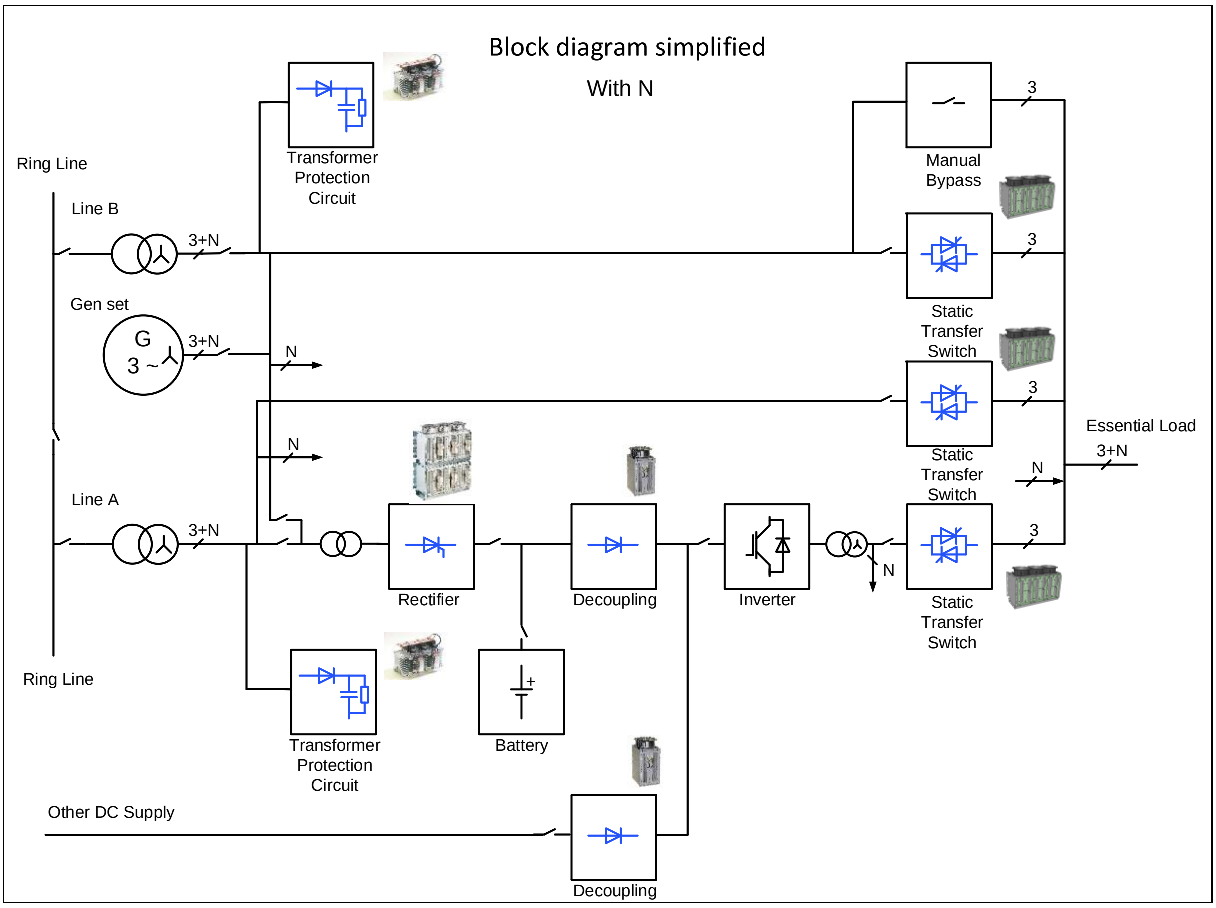


Figure 6. Block diagram for a UPS used in power plants (example)

The functional blocks in blue contain bipolar semiconductors.

2.9 Overvoltage protection

Does a UPS need transient overvoltage protection, and if so, what is the protection level required? The answer is, yes, and the IEEE Emerald Book, section 8.6.5, provides guidance on the application of Surge protection devices (SPD) for UPS equipment. The voltage protection level which is required to protect the UPS varies among manufacturers and product lines. The UPS manufacturer should be consulted for the protection levels needed for a specific UPS. In many cases, the UPS manufacturer has only conducted limited transient tests on the UPS. It may exist other design criteria on how to choose the correct performance parameters of the installed SPD on a UPS.

The semiconductors used for switching, and the capacitive and inductive components used for filtering, are directly in the path of transient overvoltages in the UPS. However, protection also needs to be provided for the control circuitry, and the components of the bypass circuitry.

Protection of the UPS is required because:

• Transient overvoltages can cause dielectric breakdown of the semiconductors in an UPS
• Dielectric breakdown causes damage to the functionality of the UPS equipment
• UPS equipment can be located at the grid feed, or in close proximity of the grid feed
• UPS equipment is designed to provide conditioned power to critical processes

Some UPS systems use metal-oxide varistors (MOVs) at the UPS input. These surge components are installed to protect the rectifier and control circuitry of the UPS. Surge components installed at this location are not adequate to protect the complete UPS system, nor are the surge components rated to protect the UPS for use in a high-availability system.

It is important to protect the UPS against the low-load behavior of the line-side transformer if the transformer is very large (> 500 kVA). A low-loaded transformer generates an overvoltage during turn-off. The voltage peak comes from high energy, and it can damage the power and control circuits of the UPS. A circuit to protect the UPS against transformer overvoltage is called "Transformer-Protection-Circuit. " Usually this circuit can also protect against line-side transients. The transients caused by the transformer are usually more critical because they are more energetic.

Usually an overvoltage protection of a system is divided in primary protection and secondary protection. The primary protection may be installed at the medium-voltage side of the transformer, the secondary protection should be installed in the UPS. It protects the UPS against transients coming from the line side or the transformer. The protection of an UPS can be achieved either by a suitable overvoltage capability of all components or by installing a dedicated protection circuit against transients at the line. Nevertheless, the topic needs to be discussed between system designer and UPS designer.

The test of such an overvoltage protection is described in IEC61000-4-5. See chapter 2.12.1.1 for details.

2.9.1 Transformer protection circuit

The circuit should protect the UPS system components against voltage transients. Thyristors in power electronic systems are usually designed for a dedicated overvoltage capability. See 2.12.1.1 for details. The voltage transients from the line-side transformer during no-load turn-off need to be clamped to the designed blocking voltage capability.

Transformer overvoltage protection can easily be achieved by using a clamping circuit as shown in Figure 7. The stored energy in the transformer is rectified by surge-current capable diodes and clamped by capacitor C (Figure 7). The capacitor needs to be designed according to the stored energy of the transformer. The capacitor must not be charged to more than 0.9* $V_{RRM, DRM}$. The rectifier must be able to carry the transient charging currents for the capacitor. Semiconductors with pressure contact technology are the preferred devices for this application. Large transient currents must be carried during operation and during turn-on (inrush current during charge of the clamping capacitor).

The advantage using this concept, instead of varistors, is the powerful clamping effect of a defined voltage level above the working voltage.

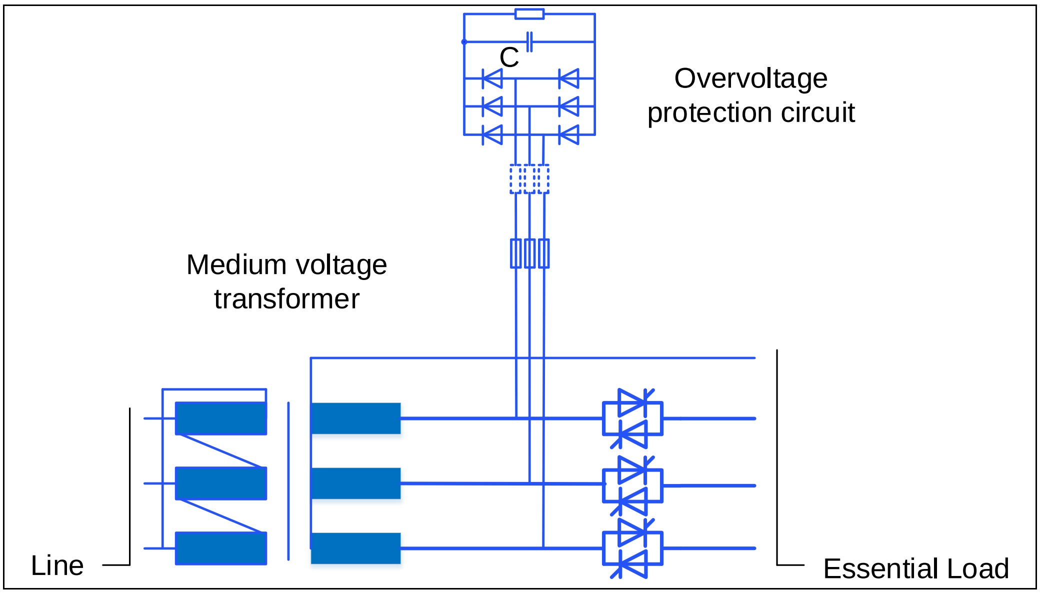


Figure 7. Clamping circuit to protect the UPS system components against overvoltage

2.9.2 Stack packages

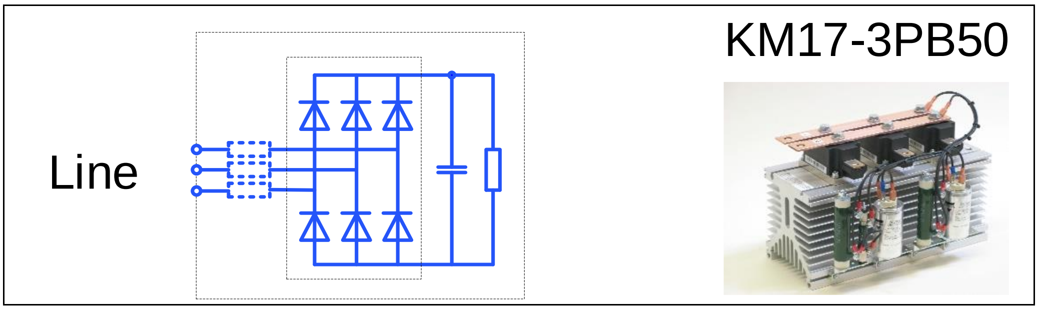


Figure 8. Circuit diagram and stack packages for transformer protection circuits

2.9.3 Selection guide

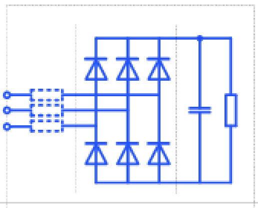
Type (Transformer Protection) (Semiconductors, heatsinks, clamping capacitors)	V Line (up to)	Transformer apparent power (approximation)	Surge Energy	Dimensions	Stack Package
					
	[Vrms]	[MVA]	[Ws]	[H*W*D, mm]	
DD175N36-KM17-R+B6U+C	1250	3.5	37	300*200*200	KM17-3PB50
DD175N36-KM17-R+B6U+C	1250	7	125	300*200*200	KM17-3PB50
DZ435N36-KM17-R+B6U+C	1250	10	150	300*200*200	KM17-6PB501
	Individual design required!				

Figure 9. Selection guide for transformer protection circuits

2.10 Input rectifier

UPS systems for power plants usually come with separate 12-pulse rectifiers and inverter units. UPS for Oil & Gas are often equipped with an integrated 12-pulse thyristor rectifier. Transformerless data-center UPS systems come with an IGBT-powered active front end to achieve a better power factor and to enable energy feedback to the grid. This feature is used e.g. for a controlled discharge of the battery or if a solar generator is used to charge the battery and feed the solar energy back to the grid.

2.10.1 Design rules

Since the battery voltage for UPS systems in industrial and power plant applications is fixed to nominal 108, 216 or 384 V_{avg}, the input rectifier needs to be designed for those DC voltages.

Since the battery must be properly charged, also at 85% of nominal line voltage (undervoltage), the transfer ratio of the mandatory input transformer needs to be defined accordingly.

(Factor 1.16 stands for battery end of charge voltage / battery nominal voltage)
(Factor 0.85 stands for correct line-side undervoltage)
(Factor 1.35 stands for DC/AC voltage factor for a 6-pulse rectifier)
(Factor 1.06 stands for transformer open-circuit voltage to transformer nominal voltage (e.g. for a transformer with a short-circuit voltage of 6%)).

The open-circuit output voltage of the transformer needs to be:

V_out transformer = V_dc_nom*1.16/0.85/1.35*1.06

Example for a 108 V battery:

V_out transformer = 108 V_{avg}*1.16/0.85/1.35*1.06

V_out transformer = 115 V_{RMS}

The design voltage of the rectifier depends on the battery voltage of the UPS system. The input rectifiers for industrial UPS systems need to be designed for the following input voltage:

Battery nominal voltage	Battery end of charge voltage	Rectifier input voltage min	Transformer open circuit voltage at 85% line voltage	Transformer open circuit voltage at nom line voltage	Comment
[V_{avg}]	[V_{avg}]	[V_{RMS}]	[V_{RMS}]	[V_{RMS}]	
108	125	93	99	114	Transformer at line side required
216	250	185	196	225	Transformer at line side required
384	445	330	350	402	With transformer at line side mainly for isolation measures.
384	445	330	330	380	For concepts w/o transformer on line side

Table 3. Internal voltages in a UPS system for 400 V_{RMS} line voltage

The values in Table 3 are valid for 400 V_{RMS} UPS systems. The UPS-system values may differ for other line voltages.

The transformer open-circuit voltage at nominal line voltage is the design line-side voltage for the thyristor rectifier.

Due to the low battery voltage of e.g. 93 V_{avg}, the DC current can reach high values for a dedicated UPS power. For a 100 kVA UPS system, for example, the rectifier must be designed for about 1500 A_{avg} (including charging current for the battery).

UPS systems for data center and IT are not considered. These systems are equipped with active front-end IGBT rectifiers. This steps up the DC-link voltage to about 800 or 960 V_{avg}. A transformer is usually not required. A transformer is required for galvanically isolated systems only.

2.10.2 Stack packages for input rectifier

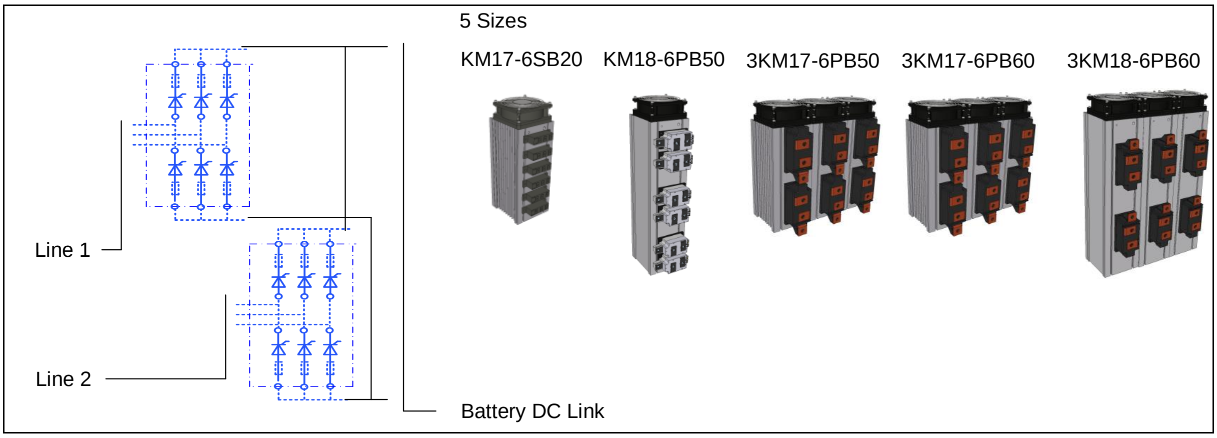


Figure 10. Circuit diagram and stack packages for rectifier stacks

2.10.3 Selection guide for rectifier stacks

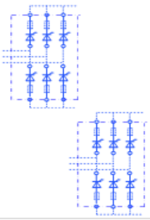
Type (Rectifier) (2B6C) (Semiconductors, heatsinks, fans and snubbers) 	Rectifier input voltage (behind transformer) up to	Nominal current @ 35°C for continuous load (no overload)	100% Current (application). Overload capability 110%-60min, 125%-30min, 150%-2min, 200%-20s. Battery charge current included.	Circuit	Rectifier power @ 108 Vavg battery voltage, 35°C for 100% load. Battery charge current included.	Rectifier power @ 216 Vavg battery voltage, 35°C for 100% load. Battery charge current included.	Rectifier power @ 384 Vavg battery voltage, 35°C for 100% load. Battery charge current included.	Dimensions	Stack Package
	[Vrms]	[Aavg]	[Aavg]		[kW @108 Vavg]	[kW @216 Vavg]	[kW @384 Vavg]	[H*W*D, mm]	
6TT60N16SOF-KM17-2B6C-LRC	400	203	152	2B6C	16	33	58	550*125*200	KM17-6SB20
6TT120N16SOF-KM17-2B6C-LRC	400	264	200	2B6C	22	43	77	550*125*200	KM17-6SB20
6TT162N16KOF-KM18-2B6C-LRC	400	542	405	2B6C	44	87	156	550*125*200	KM18-6PB34
6TT251N18KOF-3KM17-2B6C-LRC	400	871	650	2B6C	70	140	250	350*375*200	3KM17-6PB50AT
6TT500N18KOF-3KM17-2B6C-LRC	400	1142	850	2B6C	92	184	326	350*375*200	3KM17-6PB60AT
6ETT630N18KOF-3KM18-2B6C-LRC	400	1694	1270	2B6C	137	274	488	550*375*200	3KM18-6PB60ECO

Table 4. Selection guide for rectifier stacks

2.11 Decoupling diodes

2.11.1 Design rules

For UPS systems with more than one DC source, decoupling between the sources and the UPS DC-link circuit may be required. The load is usually a DC current. Only one arm is loaded.

2.11.2 Stack packages for decoupling diodes

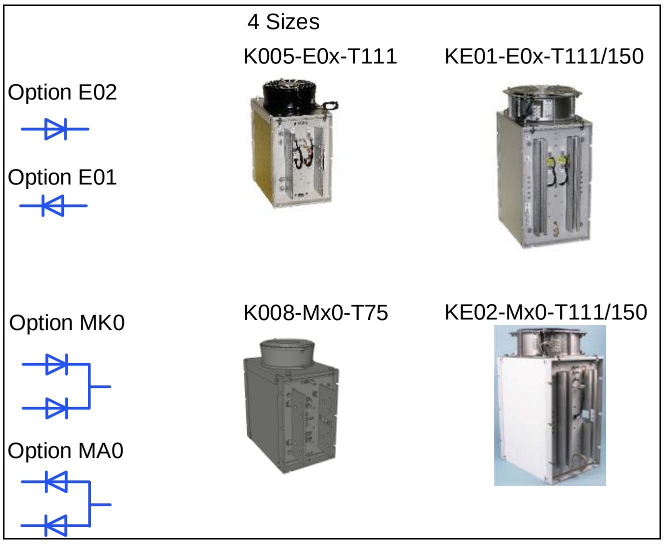


Figure 11. Stack packages for decoupling diodes

2.11.3 Selection guide for decoupling diodes

Type (Decoupling) (Semiconductors, heatsinks, fans and snubbers) 	Input voltage up to	Nominal current @ 35°C for continuous load (no overload)		Circuit	Power @ 108 Vavg battery voltage, 35°C for 100% load.	Power @ 216 Vavg battery voltage, 35°C for 100% load.	Power @ 384 Vavg battery voltage, 35°C for 100% load	Semiconductor	Dimensions	Stack Package
	[Vavg]	[Aavg]			[kW @108 Vavg]	[kW @216 Vavg]	[kW @384 Vavg]		[H*W*D, mm]	
D2450N06-K0.05-E0x-LRC	300	1570		E0x	170	339		D2450N06	333*184*380	K0.05-1T100
D5810N06-KE01-E0x-LRC	300	2415		E0x	261	522		D5810N06	527*247*380	KE01-1T150
D8320N06-KE01-E0x-LRC	300	3120		E0x	337	674		D8320N06	527*247*380	KE01-1T150
2D2450N06-K0.08-Mx0-LRC	300	1350		Mx0	146	292		2D2450N06	333*184*380	K0.08-2T75
2D5810N06-KE02-Mx0-LRC	300	2476		Mx0	267	535		2D5810N06	350*375*200	KE02-2T111
D2520N22-K0.05-E0x-LRC	1100	1755		E0x			674	D2520N22	333*184*380	K0.05-1T100
D4810N22-KE01-E0x-LRC	1100	2680		E0x			1029	D4810N22	527*247*380	KE01-1T150
2D2520N22-K0.08-Mx0-LRC	1100	1535		Mx0			589	2D2520N22	333*184*380	KE01-2T75
2D4810N22-KE02-Mx0-LRC	1100	2355		Mx0			904	2D4810N22	527*247*380	KE02-2T111

Figure 12. Selection guide for decoupling diodes

2.12 Static bypasses (SBP) and static transfer switches (STS) – (W3C)

The bypass needs to be designed according the line voltage of a UPS system. The static bypasses for all existing UPS technologies require thyristors. Since UPS systems were introduced for a wide power range (kVA to MVA) and several voltage classes, many different solutions are required to cover all applications.

In this document we differentiate between:

Designation	Description	Comment
SBP	Static bypass	Designed to work properly with the UPS
STS 1	Static transfer switch, one channel	Building block; similar to SBP but designed for larger blocking voltage due to possible phase opposition between different grid systems
STS 2	Static transfer switch, two channels	Only one channel loaded at a time
STS 3	Static transfer switch, three channels	Only one channel loaded at a time

Table 5. Overview of static bypasses and static transfer switches

The SBP can be used as an STS. The voltage requirements need to be taken into account. See chapter 2.13 for details.

2.12.1 Design rules for SBP

Important criteria for static bypasses are blocking voltage, continuous current capability, short-time-overload capability and possibly short-on-fail behavior.

2.12.1.1 Blocking voltage

Since the SBP is dedicated to work as a bypass to the UPS, the blocking voltage design can follow the typical design rules for thyristor circuits. Unusual blocking voltage requirements due to phase opposition cannot occur. With its output voltage, the UPS inverter follows the line voltage in phase and value, or is turned off.

$$\hat{V}_{line} = V_{DWM,RWM} \quad \frac{V_{DRM,RRM}}{1{,}5...2{,}5}$$

See [3] for details.

In this document and in Infineon's simulation tools, a factor of 2.2 as safety factor on RMS line voltage for voltage class selection is applied. This factor is based on long-term investigations done in the 1970s and 1980s, and on experience. Former versions of the standards VDE0160, EN50178 contained a test pulse, called "Meisenberg Pulse" (Figure 13). This transient voltage pulse should be expected on the line voltage, and converters should be able to withstand this pulse. The expected energy in the transient pulse leads to the protection circuit design. Either the converter is able to withstand the peak without any protection measure, or the peak needs to be clamped by a protection circuit. The test for this transient overvoltage capability is nowadays part of the standard EN 61000-4-5. This requirement has generated specific relations between line voltage and blocking voltage of thyristors, as listed in Table 6.

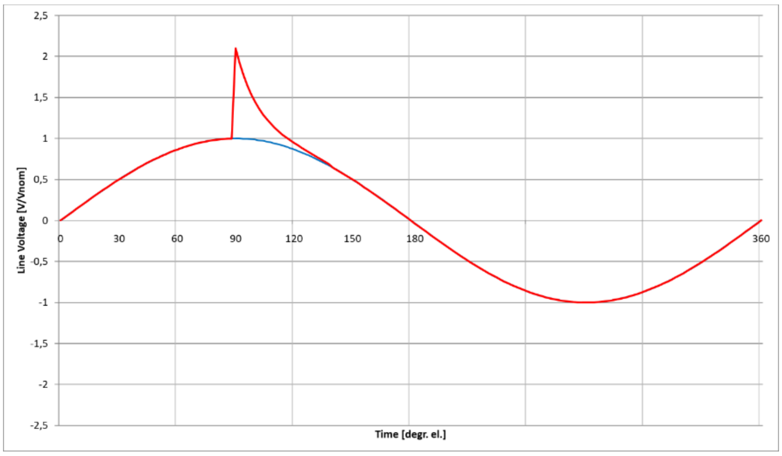


Figure 13. "Meisenberg" pulse: typical transient voltage peak on line voltage.

Line voltage [V_{RMS}]	Target Vrrm [V]	Chosen Vrrm [V]	Comment
<200	622	600	
230	715	800	
400	1244	1600	1400 Vrrm is not in focus for new designs anymore
460	1431	1600	
480	1493	1600	
500	1555	1600	
600	1866	(1800) 2200	Usage of 1800 Vrrm depends on protection against transient voltage peaks
690	2146	2200	

Table 6. Typical blocking voltage design for important line voltages

The blocking voltage design for STS is different; please see chapter 2.13 for details.

2.12.1.2 Continuous-current capability and short-time overload capability

The requirements differ for each area and application. A list with typical overload values is given in Table 7. It is not a general list, but only an example. The 1000% value, for example, is sometimes required for 10 ms only. Very often the 1000% value leads to misunderstanding. Sometimes a surge current is meant (10 ms peak current, similar to I_{TSM} of the SCR), and sometimes a short-circuit current is meant (e.g. 100 ms RMS current). It is important to note that the 125% value (30 minutes) is usually the thermal limit for an air-cooled static bypass, as the time constant of the heatsink is in that time range. The values are depicted in Figure 14. All currents are RMS currents. The colored blocks are the described requirements, the black lines indicate the technical limits. The limits are given either by the chip (peak current), the semiconductor package (thermal short time) concept, or the heatsink (thermal continuous operation). The peak current design (up to 300 ms) must follow the I_{TSM} capability of the SCR and the derating factors provided in the application note AN2012_01, chapter 3.1.14 and 3.1.15. [3] [5]. To keep the design process as simple as possible, it is advisable to select the SCR according the 10 to 300 ms current requirements. As a rule, the other requirements fit almost automatically. Nevertheless, each requirement needs to be checked. Almost each SCR has its individual limits.

Load current	Duration	Alternative	Comment
[I/I_nom (A_{RMS})]			
100%	24/7 h		Not a limit, converter is designed for 125%
110%	60 min	106%	Not a limit, converter is designed for 125%
125%	30 min	10 min	30 min is the time constant of a typical heatsink. Therefore, the 125% value is the continuous current required for the design of the bypass.
150%	2 min	1 min	
200%	20 s		
500%	250 ms	700%, 0.6s or 600%, 0.05s	Short-circuit current. Do not confuse this with surge current. Sometimes this is the limiting parameter. It depends on SCR package technology (solder vs. pressure contact).
1000%	100 ms	10 ms (one sine half wave) or 20 ms	Short-circuit current. Do not confuse this with surge current. Usually this is the limiting parameter. It depends on the SCR package technology (solder vs. pressure contact).

Table 7. An example of current capability (RMS) for static bypasses.

Surge current	Duration	Alternative	Comment
[Sine peak value (A)]			
1000%	10 ms	8.33 ms for 60 Hz	Surge current. Do not confuse this with short-circuit current. This is related to the nominal (100%) sine peak value. Sometimes 20 ms (16.67 ms) are requested. Each SRC in the W1C circuit takes over one sine half wave. The surge current for 60 Hz is perhaps 5% more.

Table 8. Surge current capability for static bypasses.

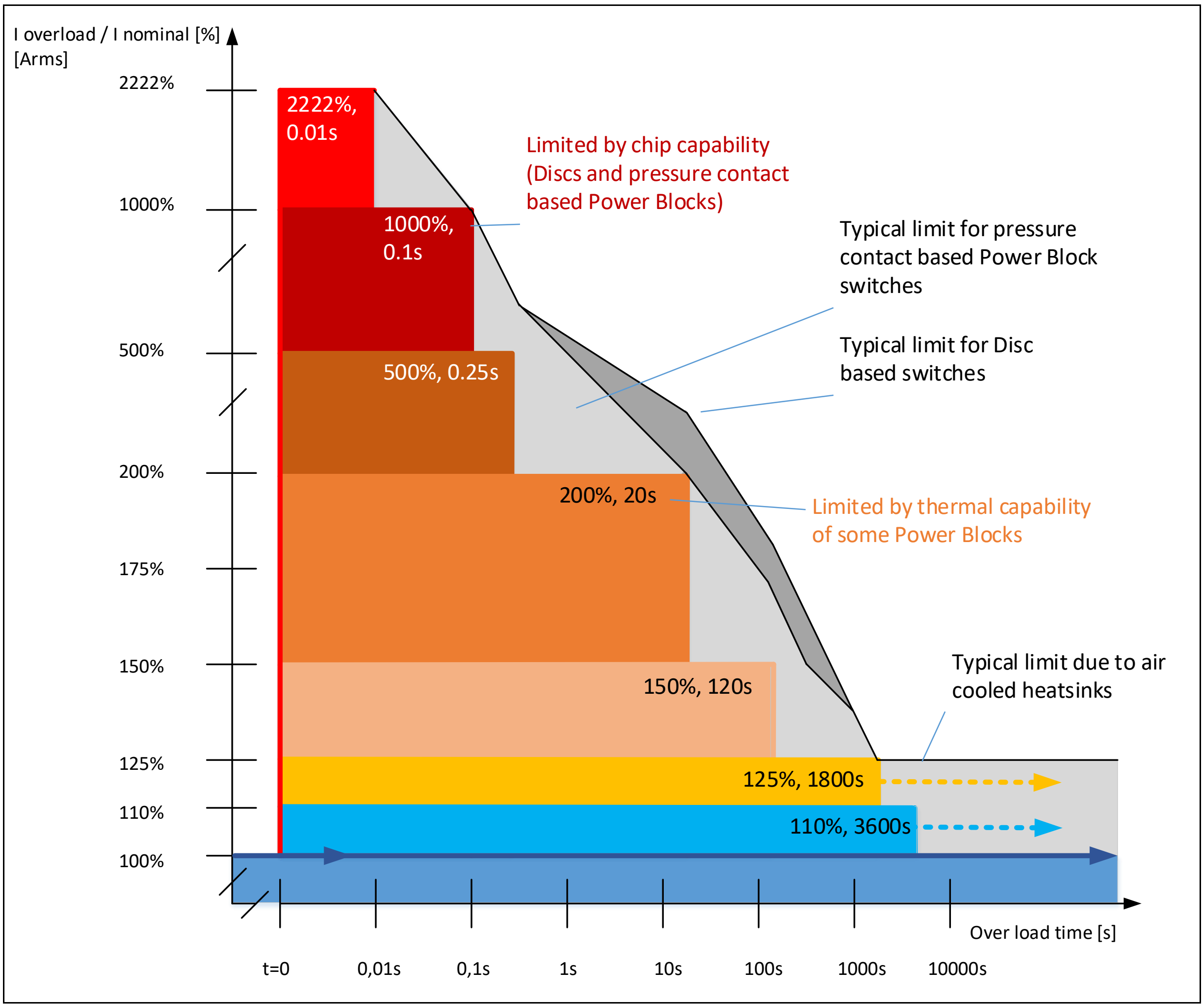


Figure 14. Example for overload requirements and typical capabilities of SCR stacks

SCRs based on the pressure-contact technology are the most robust against short-time overload. In case of a malfunction, SCRs with pressure-contact technology stay shorted (short-on-fail behavior). That may be an additional advantage.

The snubber circuits need to be designed according to the required overload.

2.12.2 Stack packages for SBP and one-channel STS (STS 1)

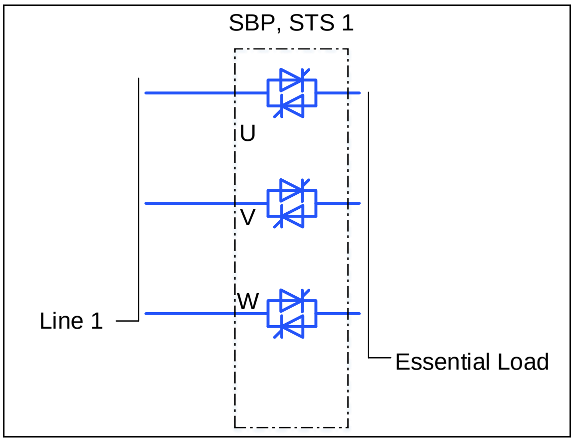


Figure 15. Circuit diagram for SBP and one-channel STS (STS 1)

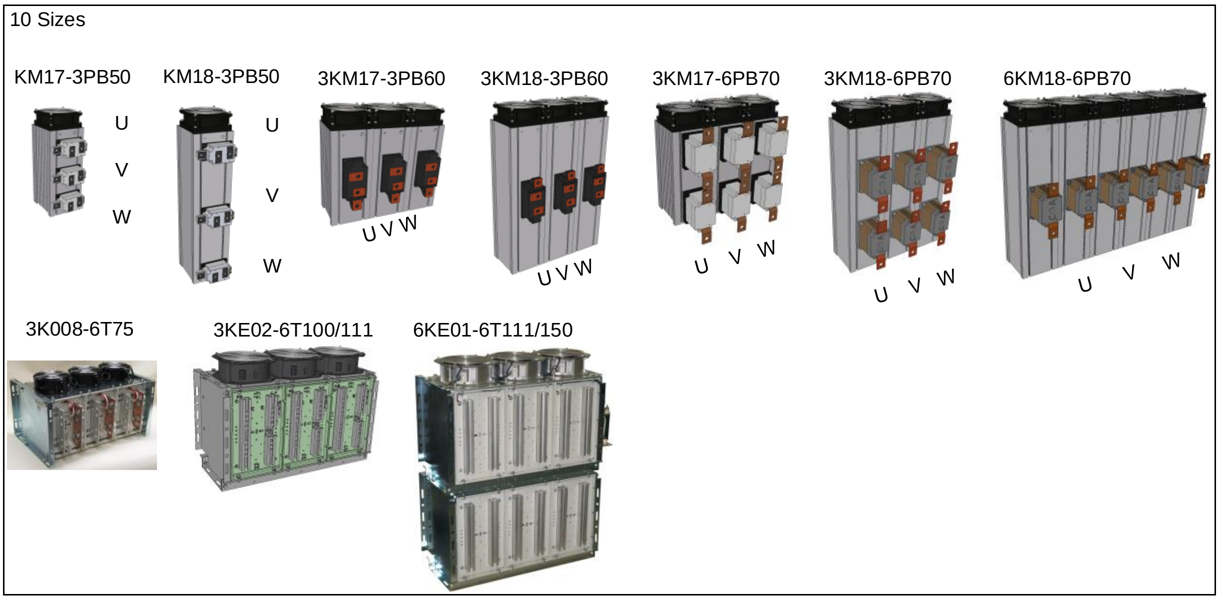


Figure 16. Stack packages for SBP and STS 1

2.12.3 Selection guide for SBP and one-channel STS (STS 1)

The suitable line voltage for SBP is given in column 2. The suitable line voltage for STS is given in column 3 and 4. It depends on the grid system. See chapter 2.13.1.2 for details.

The type designation in column 1 is a fictitious example, indicating the embedded SCRs, the heatsink, the circuit diagram and included options. The fictitious stack package designation in the right column contains heatsink and SCR package designation.

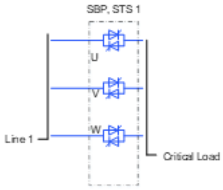
Type (SBP, STS 1) (W3C) (Semiconductors, heatsinks, fans and snubbers) 	SBP V line	STS with N (TN, TT system) V line	STS w/o N (IT system) V line	Nominal current @ 35°C, nom airflow for continuous load (no overload)	100% Current at 40°C (application). Overload capability at 35°C: 110%-60min, 125%-30min, 150%-2min, 200%-20s, 500%-250ms,	Surge current 10ms (I_TSM warm)	Apparent Power SBP	Apparent Power STS with N (TN, TT system)	Apparent Power STS w/o N (IT system)	Dimensions	Stack Package
	[Vrms]	[Vrms]	[Vrms]	[Arms]	[Arms]	[kA]	[kVA]	[kVA]	[kVA]	[H*W*D, mm]	
3TT250N16KOF-KM17-W3C-LRC	400	400	300	281	212	7	147	147	110	350*125*200	KM17-3PB50AT
3TT500N16KOF-3KM17-W3C-LRC	400	400	300	631	444	15	308	308	231	350*375*200	3KM17-3PB60AT
3TT330N16KOF-KM18-W3C-LRC	500	400	300	411	275	10	238	191	143	550*125*200	KM18-3PB50AT
3TT600N16KOF-3KM17-W3C-LRC	500	400	300	706	500	18	433	346	260	350*375*200	3KM17-3PB60AT
3TT820N16KOF-3KM17-W3C-LRC	500	400	300	794	635	20	550	440	330	350*375*200	3KM17-3PB60AT
6TZ860N16KOF-6KM18-W3C-LRC	500	400	300	1009	807	40	699	559	419	550*750*200	6KM18-6PB70AT
3ETT630N18P60-3KM17-W3C-LRC	600	500	300	663	467	15	486	405	243	350*375*200	3KM17-3PB60ECO
6TZ800N18KOF-3KM18-W3C-LRC	600	500	300	760	608	30	632	527	316	550*375*200	3KM18-6PB70AT
6TZ800N18KOF-6KM18-W3C-LRC	600	500	300	969	775	30	806	671	403	550*750*200	6KM18-6PB70AT
6T1900N18TOF-3K008-W3C-LRC	600	500	300	1655	1040	34	1081	901	540	333*552*380	3K008-6T75
6T2600N18TOF-3KE02-W3C-LRC	600	500	300	2640	1200	38	1247	1039	624	527*741*380	3KE02-6T100
6T3800N18TOF-3KE02-W3C-LRC	600	500	300	3304	1800	57	1871	1559	935	527*741*380	3KE02-6T111
3TT260N22KOF-KM18-W3C-LRC	690	600	400	357	252	8	301	262	175	550*125*200	KM18-3PB50AT
3ETT540N22P60-3KM17-W3C-LRC	690	600	400	594	420	13	502	436	291	350*375*200	3KM17-3PB60ECO
3TT700N22KOF-3KM17-W3C-LRC	690	600	400	706	544	17	650	565	377	350*375*200	3KM17-3PB60AT
6TZ740N22KOF-3KM18-W3C-LRC	690	600	400	760	608	27	727	632	421	550*375*200	3KM18-6PB70AT
6T1330N22TOF-3K008-W3C-LRC	690	600	400	1324	732	23	875	761	507	333*552*380	3K008-6T75
6T1960N22TOF-3KE02-W3C-LRC	690	600	400	2182	1112	35	1329	1156	770	527*741*380	3KE02-6T100
6T2810N22TOF-3KE02-W3C-LRC	690	600	400	2645	1588	50	1898	1650	1100	527*741*380	3KE02-6T111
6TZ310N26KOF-3KM17-W3C-LRC	900	690	500	477	252	8	393	301	218	350*375*200	3KM17-6PB501
6TZ400N26KOF-3KM17-W3C-LRC	900	690	500	556	348	11	542	416	301	350*375*200	3KM17-6PB501
6TZ630N28KOF-3KM17-W3C-LRC	1000	690	600	709	567	23	982	678	589	350*375*200	3KM17-6PB70
6T1220N28TOF-3K008-W3C-LRC	1000	690	600	1204	715	23	1239	855	743	333*552*380	3K008-6T75
6T1590N28TOF-3KE02-W3C-LRC	1000	690	600	1763	888	28	1538	1061	923	527*741*380	3KE02-6T100
6T2480N28TOF-6KE01-W3C-LRC	1000	690	600	2855	1384	44	2397	1654	1438	962*741*380	6KE01-6T111
6T4771N28TOF-6KE01-W3C-LRC	1000	690	600	3781	2778	91	4811	3320	2887	962*741*380	6KE01-6T150
3TT240N38KOF-3KM17-W3C-LRC	1250	1000	690	363	174	6	378	302	208	350*375*200	3KM17-3PB60
6TZ530N36KOF-3KM17-W3C-LRC	1250	1000	690	625	475	20	1029	823	568	350*375*200	3KM17-6PB70
6T930N36TOF-3K008-W3C-LRC	1250	1000	690	1064	556	18	1204	963	664	333*552*380	3K008-6T75
6T1800N38TOF-3KE02-W3C-LRC	1250	1000	690	1679	1304	41	2823	2259	1558	527*741*380	3KE02-6T111
6T3801N36TOF-6KE01-W3C-LRC	1250	1000	690	3386	2200	87	4763	3811	2629	962*741*380	6KE01-6T150

Table 9. Selection guide for SPB and one-channel STS (STS 1)

The stacks in Table 9 are designed for static bypasses. They can also be used for static transfer switches. Due to the other blocking voltage requirements, and possible phase opposition in STS circuits, the line voltage needs to be limited to the value in column 3 or 4, depending on the grid system.

2.12.4 Building block designs for individual circuits and set-ups (e.g. W1C)

For more flexibility, cooling blocks (W1C) can be extracted from the disc-based W3C stacks described in chapter 2.12.2.

W1C stacks built from Power Blocks with package PB50, PB60, PB70 are available on request.

Figure 17. Stack packages for W1C circuits (building blocks for individual systems)

2.12.5 Selection guide for building block designs

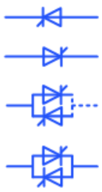
Blocks for individual designs (SBP, STS 1) (Semiconductors, heatsinks, fans and snubbers) E01 E02 V00 P00 	SBP V line	STS with N (TN, TT system) V line	STS w/o N (IT system) V line	Nominal current @ 35°C, nom airflow for continuous load (no overload)	100% Current at 40°C (application). Overload capability at 35°C: 110%-60min, 125%-30min, 150%-2min, 200%-20s, 500%-250ms, 1000%-100ms	Surge current 10ms (I_TSM warm)	Apparent Power SBP (three phase)	Apparent Power STS with N (TN, TT system) (three phase)	Apparent Power STS w/o N (IT system) (three phase)	Dimensions	Stack Package
	[Vrms]	[Vrms]	[Vrms]	[Arms]	[Arms]	[kA]	[kVA]	[kVA]	[kVA]	[H*W*D, mm]	
2T1900N18TOF-K008-V00-LRC	600	500	300	1655	1040	34	1081	901	540	333*184*380	K008-2T75
2T2600N18TOF-KE02-V00-LRC	600	500	300	2640	1200	38	1247	1039	624	527*247*380	KE02-2T100
2T3800N18TOF-KE02-V00-LRC	600	500	300	3304	1800	57	1871	1559	935	527*247*380	KE02-2T111
2T1220N28TOF-K008-V00-LRC	1000	690	600	1204	715	23	1239	855	743	333*184*380	K008-2T75
2T1590N28TOF-KE02-V00-LRC	1000	690	600	1763	888	28	1538	1061	923	527*741*380	KE02-2T100
2T1590N28TOF-KE02-P00-LRC	1000	690	600	1763	888	28	1538	1061	923	527*741*380	KE02-2T100-S07
T2480N28TOF-KE01-E0x-LRC	1000	690	600	2855	1384	44	2397	1654	1438	962*741*380	KE01-T111
T4771N28TOF-KE01-E0x-LRC	1000	690	600	3781	2778	91	4811	3320	2887	962*741*380	KE01-T150
2T930N36TOF-K008-V00-LRC	1250	1000	690	1064	556	18	1204	963	664	333*552*380	K008-2T75
2T1800N38TOF-KE02-V00-LRC	1250	1000	690	1679	1304	41	2823	2259	1558	527*741*380	KE02-2T111
2T1800N38TOF-KE02-P00-LRC	1250	1000	690	1679	1304	41	2823	2259	1558	527*741*380	KE02-2T111-S07
T3801N36TOF-KE01-E0x-LRC	1250	1000	690	3386	2200	87	4763	3811	2629	962*741*380	KE01-T150

Table 10. Selection guide for building block designs

2.13 Static transfer switches (STS) (W3C)

2.13.1 Design rules

Static transfer switches seem to be similar to static bypasses. However, some further requirements need to be fulfilled. Most rules for STS design are similar to the rules for SBP; see chapter 2.12.1 for details. Regarding cooling and blocking-voltage capability, the approaches may be different. If an STS consists of two or three channels, these can be installed on the same heatsink, because only one channel will be loaded. Furthermore, if an STS with two channels can be faced to line voltage in

phase opposition, the blocking voltage of the semiconductors needs to be designed for that higher voltage.

2.13.1.1 Cooling

The cooling for SBP and STS with only one channel is identical. For STS with 2 or 3 channels, the cooling can be simplified, because only one channel is in operation. The cooling needs to be designed for one channel only. But there must be enough space on the heatsink to install the SCRs for two or three channels.

2.13.1.2 Blocking voltage design

An STS system may be faced with phase opposition between the feeding lines. The STS in opened condition is faced with a higher working voltage than evaluated with the standard rule. See chapter 2.12.1.1 for details.

2.13.1.3 Working voltage for STS in TT, TN systems

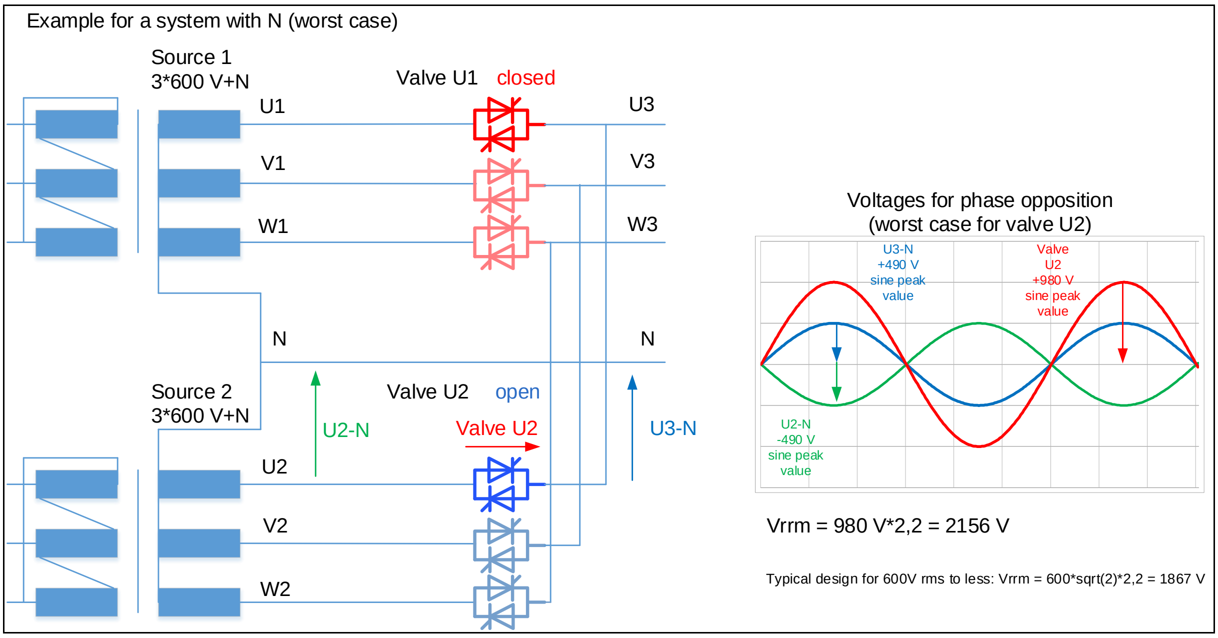


Figure 18. Blocking voltage design for systems with N (TN, TT system)

2.13.1.4 Working voltage for STS in IT systems

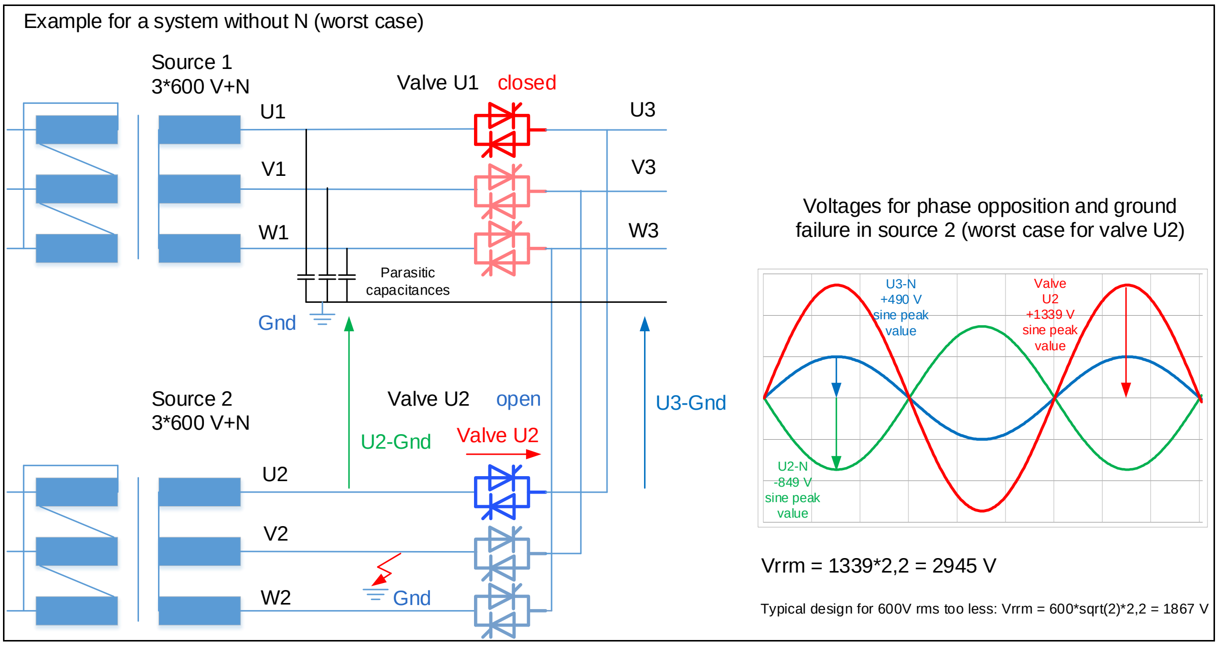


Figure 19. Blocking voltage design for systems w/o N (IT system)

The higher working voltage must be taken into account. The suitable line voltage for STS is given in columns 3 and 4 in the selection guide tables.

2.13.2 One-channel static transfer switch (STS 1, building block for large systems)

See chapter 2.12.2 for details.

2.13.3 Selection guide for STS with one channel (STS1)

See chapter 2.12.3 for details.

2.13.4 Two--channel static transfer switch (STS 2)

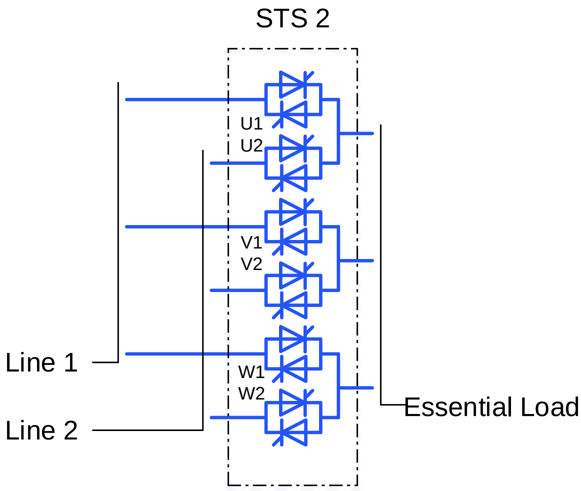


Figure 20. Circuit diagram for two-channel W3C static transfer switch (STS 2)

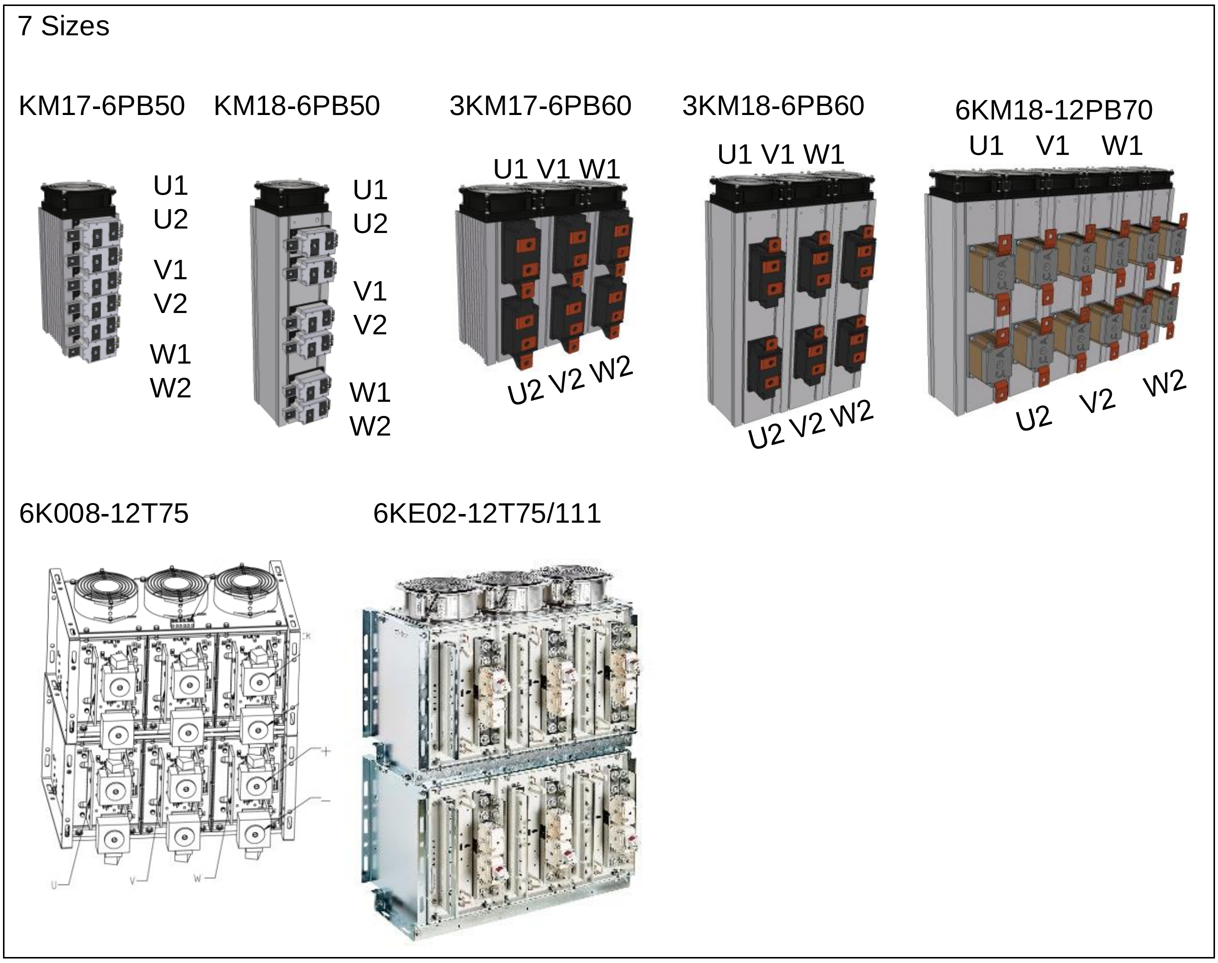


Figure 21. Stack packages for two-channel W3C STS (STS 2)

2.13.5 Selection guide for STS with two channels (STS 2)

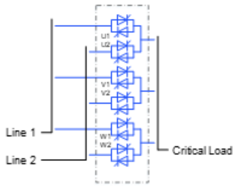
Type (STS 2) (2W3C) (Semiconductors, heatsinks, fans and snubbers) 	STS with N (TN, TT system) V line	STS w/o N (IT system) V line	Nominal current @ 35°C, nom airflow for continuous load (no overload)	100% Current at 40°C (application). Overload capability at 35°C: 110%-60min, 125%-30min, 150%-2min, 200%-20s, 500%-250ms, 1000%-100ms	Surge current 10ms (I_TSM warm)	Apparent Power STS with N (TN, TT system)	Apparent Power STS w/o N (IT system)	Dimensions	Stack Package
	[Vrms]	[Vrms]	[Arms]	[Arms]	[kA]	[kVA]	[kVA]	[H*W*D, mm]	
6TT250N16KOF-KM17-2W3C-LRC	400	300	281	212	7	147	110	350*125*200	KM17-6PB50AT
6TT500N16KOF-3KM17-2W3C-LRC	400	300	631	444	15	308	231	350*375*200	3KM17-6PB60AT
6TT330N16KOF-KM18-2W3C-LRC	400	300	411	275	10	191	143	550*125*200	KM18-6PB50AT
6TT600N16KOF-3KM17-2W3C-LRC	400	300	706	500	18	346	260	350*375*200	3KM17-6PB60AT
6TT820N16KOF-3KM17-2W3C-LRC	400	300	794	635	20	440	330	350*375*200	3KM17-6PB60AT
12TZ860N16KOF-6KM18-2W3C-LRC	400	300	1009	807	40	559	419	550*750*200	6KM18-12PB70AT
6ETT630N18P60-3KM17-2W3C-LRC	500	300	663	467	15	405	243	350*375*200	3KM17-6PB60ECO
12TZ800N18KOF-6KM18-2W3C-LRC	500	300	969	775	30	671	403	550*750*200	6KM18-12PB70AT
12T1900N18TOF-6K008-2W3C-LRC	500	300	1986	1040	34	901	540	616*552*380	6K008-12T75
12T2600N18TOF-6KE02-2W3C-LRC	500	300	2597	1200	38	1039	624	962*741*380	6KE02-12T100
12T3800N18TOF-6KE02-2W3C-LRC	500	300	3960	1800	57	1559	935	962*741*380	6KE02-12T111
6TT260N22KOF-KM18-2W3C-LRC	600	400	357	252	8	262	175	550*125*200	KM18-6PB50AT
6ETT540N22P60-3KM17-2W3C-LRC	600	400	594	420	13	436	291	350*375*200	3KM17-6PB60ECO
6TT700N22KOF-3KM17-2W3C-LRC	600	400	706	544	17	565	377	350*375*200	3KM17-6PB60AT
12T1040N22TOF-6K008-2W3C-LRC	600	400	1435	588	19	611	407	616*552*380	6K008-12T75
12T1330N22TOF-6K008-2W3C-LRC	600	400	1582	730	23	759	506	616*552*380	6K008-12T75
12TZ310N26KOF-3KM17-2W3C-LRC	690	500	477	252	8	301	218	350*375*200	3KM17-12PB501
12TZ400N26KOF-3KM17-2W3C-LRC	690	500	556	348	11	416	301	350*375*200	3KM17-12PB501
12T1220N28TOF-6K008-2W3C-LRC	690	600	1441	715	23	855	743	616*552*380	6K008-12T75
12T1590N28TOF-6KE02-2W3C-LRC	690	600	1999	888	28	1061	923	962*741*380	6KE02-12T100
6TT240N38KOF-3KM17-2W3C-LRC	1000	690	363	172	6	298	206	350*375*200	3KM17-6PB60
12T930N36TOF-6K008-2W3C-LRC	1000	690	1255	552	18	956	660	616*552*380	6K008-T75
12T1800N36TOF-6KE02-2W3C-LRC	1000	690	2230	1300	41	2252	1554	962*741*380	6KE02-12T111
			For larger currents use combinations from STS 1						

Table 11. Selection guide for two-channel W3C STS (STS 2)

2.13.6 Three-channel static transfer switch (STS 3)

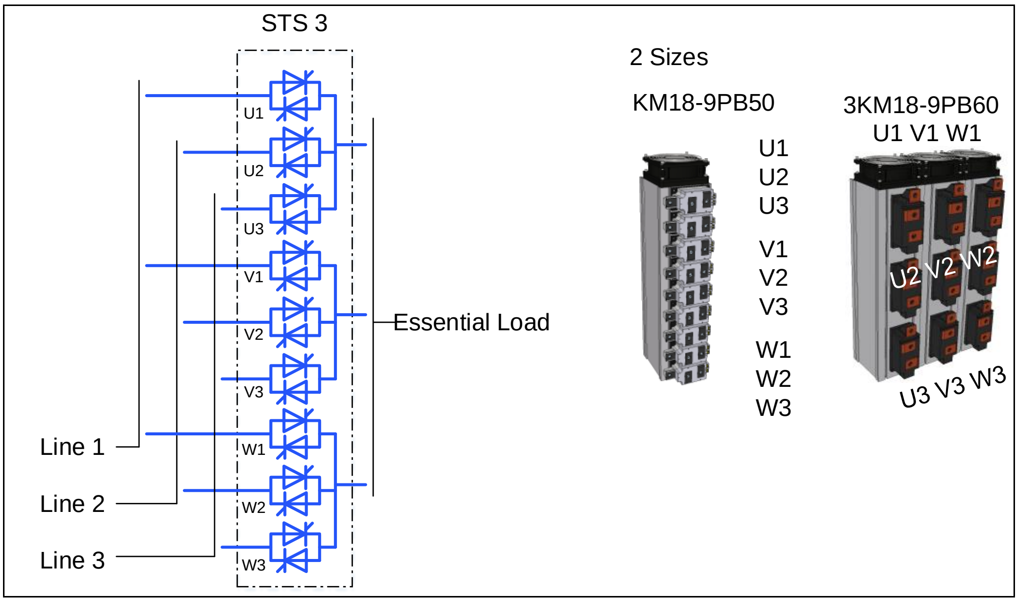


Figure 22. Circuit diagram and stack packages for three-channel W3C STS (STS 3)

2.13.7 Selection guide for STS with three channels (STS 3)

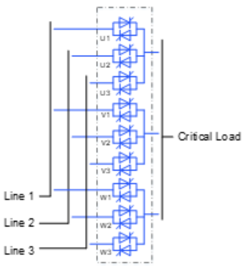
	Proposed max. line voltage acc. application									
Type (STS 3) (3W3C) (Semiconductors, heatsinks, fans and snubbers) 	STS with N (TN, TT system) V line	STS w/o N (IT system) V line	Nominal current @ 35°C for continuous load (no overload)	100% Current (application). Overload capability 110%-60min, 125%-30min, 150%-2min, 200%-20s, 500%-250ms, 1000%-100ms	Surge current 10ms (I_TSM warm)		Apparent Power STS with N (TN, TT system)	Apparent Power STS w/o N (IT system)	Dimensions	Stack Package
	[Vrms]	[Vrms]	[Arms]	[Arms]	[kA]		[kVA]	[kVA]	[H*W*D, mm]	
9TT250N16KOF-KM18-3W3C-LRC	400	300	358	220	7		152	114	550*125*200	KM18-9PB50AT
9TT500N16KOF-3KM18-3W3C-LRC	400	300	692	460	15		319	239	550*375*200	3KM18-9PB60AT
9TT330N16KOF-KM18-3W3C-LRC	400	300	411	265	10		183	138	550*125*200	KM18-9PB50AT
9TT820N16KOF-3KM18-3W3C-LRC	400	300	875	638	20		442	332	550*375*200	3KM18-9PB60AT
9TT260N22KOF-KM18-3W3C-LRC	600	400	357	252	8		262	175	550*125*200	KM18-9PB50AT
9TT700N22KOF-3KM18-3W3C-LRC	600	400	775	544	17		565	377	550*375*200	3KM18-9PB60AT
			For larger currents use combinations from STS 1 or STS 2							

Table 12. Selection guide for three-channel W3C STS (STS 3)

3 Solution tree for UPS systems

The design and assembly of components of a UPS system depends on the individual requirements. The following table shows a selection of semiconductors and assemblies, apart from the examples in this document, which can be used in UPS systems [7].

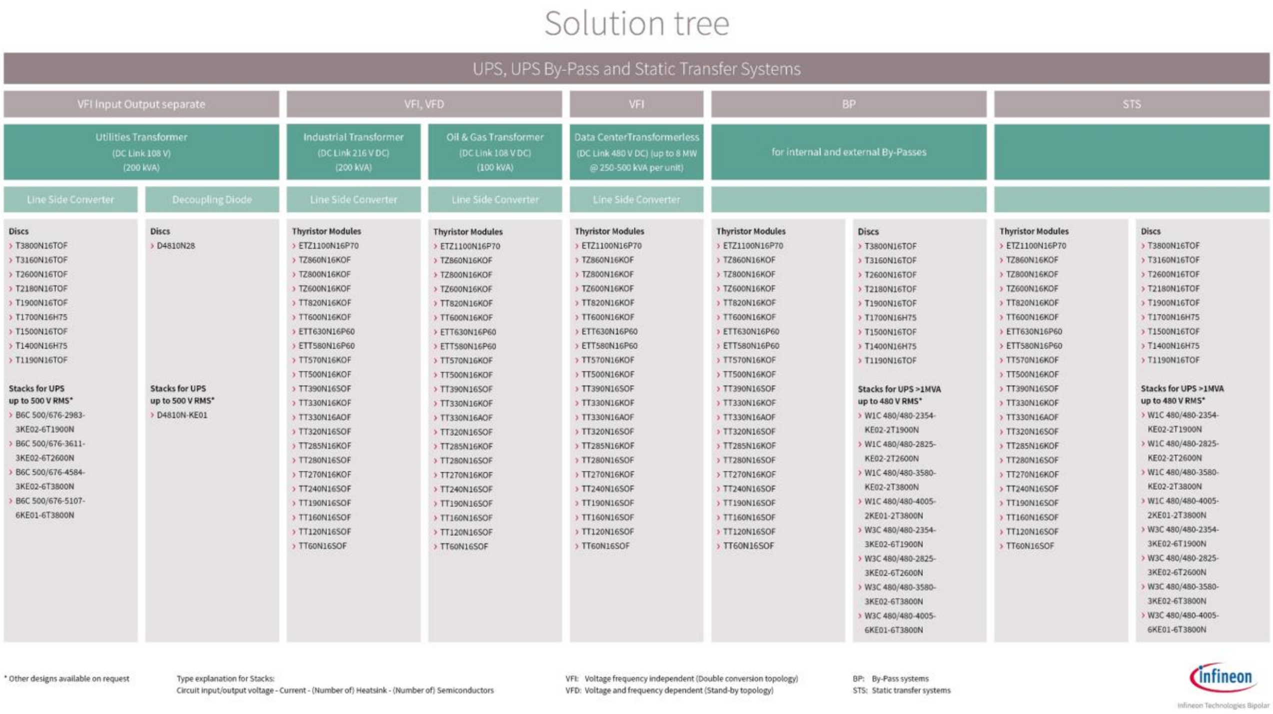


Figure 23. Solution tree for UPS systems

Please find the original solution tree and more details about bipolar semiconductors in UPS systems on our web site.

Figure 24. QR Code for the UPS solution tree

4 Conclusion

Bipolar power semiconductors are used in important functional groups of a modern UPS system. Since the technology is less complex compared to IGBTs, the failure rate of bipolar semiconductors is very low. Therefore, and because of fewer power losses, high-power UPS systems (like data center UPS) are usually operated in bypass mode (via thyristors). The inverter is in stand-by, and starts operating only in case of a line failure. Based on the use of robust bipolar thyristors and the stand-by operating mode, the UPS provides high reliability, has fewer power losses, and comes close to perfection.

5 Figures

6 Tables

7 References

[1] IEC, 2011. IEC 62040-3 – Uninterruptible power systems (UPS) – Part 3.

[2] Infineon Technologies AG, 2020. UPS application overview_20200616_v3.

[3] Infineon Technologies Bipolar GmbH&Co.KG., 2012. AN2012-01 Technical Information-AN-v1.0-en.

[4] Infineon Technologies Bipolar GmbH&Co.KG., 2017. In perfect harmony with Infineon Power Stacks.

[5] Infineon Technologies Bipolar GmbH&Co.KG., 2020. Online shop for bipolar power semiconductors. https://www.ifbip-shop.com

[6] Infineon Technologies Bipolar GmbH&Co.KG., 2020. The System Line. Assemblies for bipolar semiconductors and well-known cooling technologies.

[7] Infineon Technologies Bipolar GmbH&Co.KG., 2020. Solution tree for bipolar semiconductors in UPS applications.

[8] Infineon Technologies Bipolar GmbH&Co.KG., 2020. Technical information sTT2200N18P55