Guidance for the application of low voltage fuses
IEC 60269-5 Technical Report, Ed 2.0

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Introduction

A modern application guide for fuses is available by the International Electrotechnical Commission. The application guide can be used for reference and quoting purposes as it made by the fuse experts of IEC. It gives good practice for using fuses.

The Technical Report IEC 60 269 – 5: "Low Voltage Fuses – Part 5: Guidance for the application of low voltage fuses" was first published as Edition 1.0 in September 2010 [1]. It covered the following subjects

- Terms and definitions
- Fuse benefits
- Fuse construction and operation
- Fuse combination units
- Fuse selection and markings
- Conductor protection
- Selectivity of protective devices
- Short circuit damage protection
- Protection of power factor correction capacitors
- Transformer protection
- Motor circuit protection
- Circuit breaker protection
- Protection of Semiconductor Devices
- Fuses in enclosures
- DC applications
- Automatic disconnection for protection against electrical shock
- Coordination between fuses and contactors/motor-starters

Due to a rather quick development in some areas of electricity production and use, it was necessary to start a new process to maintain, amend and add some more guidance into the existing report.

A number of subjects were named for maintenance respectively to add in an amendment.

- Fuse operation in higher altitude
- DC applications
- Photovoltaic applications
- Protection of wind mills
- Editorial corrections and improvements

Already at the beginning of the work, it was found out, that the content added would by far exceed the maximum number of pages IEC allowed for an amendment. Therefore an Edition 2.0 was published in March 2014.

Fuse benefits

Three items were added to fuse benefits, as they were not spelled out before and do have significant influence in today's systems

- Improved power quality, as current limiting fuses break high currents within milliseconds. Dips and sags in the system supply voltages are minimized
- High level of energy efficiency as the power dissipation of a fuse is very low compared with other protection devices and results to much less than 0,1% of the power transmitted by rated current
- Excellent and equipment protection in case of arc flash: It takes only few milliseconds for a properly sized current limiting fuse in its current limiting range to interrupt an arcing fault and therefore to keep arc energy well below hazardous or damaging levels.

Fuse operation in higher altitudes

The use of electric energy in higher altitudes has increased e.g. due to cable railways, chair lifts, skiing resorts, snow making in Europe and also due to increased quality industrial installation in developing countries.
For example in Austria, there are snow guns and snow making machines installed and authorized to up to 3000m above sea level.
The cool surrounding air and the lower air pressure influence the current carrying capacity of the fuse as well as the cable.
These influences led the experts of SC 32B /MT 8 to create derating factors for different altitudes
The factors can be seen in table 1 as well as calculated by the formula

$$\frac{I}{I_n} = 1 - \frac{h - 2000}{100} \times \frac{0,5}{100}$$

I….maximum current carrying capacity at altitude h
In….rated current up to 2000m
h….altitude in meters

Fuse combination units

Fuse combination units are the devices that connect the protection function of the fuse with the switching function, mostly in form of integral units and therefore fulfil the functions of

- Switching under load
- Isolation
- short circuit protection

and in some cases also the overload protection.

The definitions of theses fuse combination units have been extended in [2] and therefore fitted also into the fuse guide. The best overview can be taken from Table 2.

The new table (see Table 2) and the definitions now show a differentiation between single break and double break units. Double break units can insure a voltage free removal of the fuse link, when the necessary isolation requirements are met.

New utilization categories

2 new utilization categories were taken into account. Category gPV, the fuse for photovoltaic applications and in a new chapter (see par. 8) the guidance to this application was added. The other category is gK (see diagram 1), which is an enlargement of the rated current range for general purpose low voltage fuses. The rated current range is extended up to 4800A with the usual steps of 1600A, 2000A, 2500A, 3200A, 4000A and 4800A. The minimum breaking capacities required are 200 kA for smaller than 500V a.c rated voltage, 160 kA at 690V a.c. and 100 kA at 500 V.d.c. The selectivity ratio between gK fuses is 1:1,6 for overcurrent selectivity within this utilization category. The selectivity ratio to fuses of gG utilization category is 1: 3,2

Operational voltage of fuse links

The operational voltage of fuses is always a question, since the rated voltage a fuse is given by the manufacturer and only a hint for the maximum operational voltage.

For North American systems of fuses (e.g. gN and gD), the operational voltage must not exceed the rated voltage, regardless of a.c. or d.c. For all other characteristics within the IEC standard 60 269 the operational voltage may exceed the rated voltage by a maximum of 10% for a.c. application.

For d.c. application, the maximum operational voltage must be seen together with the time constant. Therefore the typical maximum d.c. operational voltages are mentioned in a table (see Table 3) with the time constants mentioned.

Two new tables (see Table 4 and 5) now sum up this information in the fuse guide.

In principle the maximum system voltage should not exceed the rated voltage of the fuse link and should be chosen accordingly. The test voltage mentioned in the standard IEC 60269 -1 to -4 and -6 should be reserved for allowable system deviations and for the safety factor built into these products. Additionally the time constant of the short circuit in the system should be observed.

Protection of semiconductor devices

The fuse utilization category gS and gR are relatively new in IEC 60 269-4 [4]. The gR fuse optimizes low I^2t, but has high power dissipation and is therefore not easily applicable in fuse combination units. Utilization category gS is optimized for low power dissipation and is compatible with standardized fuse bases and fuse combination units.

A table showing the difference of the non-fusing current with $1{,}25 \cdot I_n$ for the gS fuse and $1{,}13 \cdot I_n$ for the gR fuse. Both values are connecting with the applicable conventional time.

Photovoltaic (PV) system protection

a) General information

Due to the rapid development of PV systems the protection of these systems against overcurrent is a major cause for fuses. The design and standardization of specific PV fuses, utilization category gPV improved the protection of PV systems.

A full chapter of the new guide is focused on PV applications. Unfortunately up to now the TC 64 of IEC has not decided on the required minimum non tripping and tripping current required. One of the reasons, that there is no maintenance of IEC 60269-6 [5] at the moment.

PV systems consist of the PV module as the smallest unit. These modules are connected in series to form a “string” to reach higher voltages. The “strings” are connected in parallel to arrays or subarrays dependent on the size of the PV system to reach higher current levels. PV systems generate direct current and these must be changed into alternate current to feed the energy to the power grid. For this reason inverters are a part of the system. Since PV systems only generate electricity when the sun is present, some systems do have storage systems, such as batteries, to ensure continuous supply.

The basic parameters of PV systems can be seen in Figure 1 and show, that the d.c. source is totally different from a linear d.c. source.

The inherently current limiting nature of PV modules, enables them to carry their rated short circuit current $I_{SC,STC}$ and overcurrents due to high irradiance without any limitation. $I_{SC,STC}$ defines the short circuit current under test conditions. Test conditions are defined as a PV cell temperature of 25°C, irradiance of 1000W / m^2 and a relative air mass AM = 1,4. There is no need of protection of the cell for the module’s forward current.

This is different for module reverse currents exceeding the $I_{MOD,\ REVERSE}$ as given by the manufacturer. Shading, faulty modules and other conditions can lead to a reverse fault current, which may have damaging effects such as

- Permanent damage to modules
- Reduced efficiency
- Damaged conductors
- Electric arcs and fire

Protection can be achieved by a fuse installed in series in each string against reverse currents.

A fuse should also be installed in each array conductor to prevent overloading of interconnecting cables and wires.

It is pointed out, that the protection of the PV strings, arrays and interconnecting conductors against overcurrents, does not include the protection of other equipment, which might be part of the specific system, such as batteries, converters or capacitors. These must be protected by their overcurrent protection.

b) Selection of PV fuse links

For PV installations only utilization category gPV should be used. All other utilization categories do not fulfil the necessary requirements.

$I_{MOD,\ REVERSE}$ is the withstand capability of the module against reverse currents and the basis for selection of the fuse link. String fuses are not required with only one or two modules in parallel, since the reverse current does not reach not unpermitted levels. Attention has to be focused on the rating of the string cables and if needed a fuse link should protect the cable. If there are three or more strings connected in parallel fuse protection is required.

For unearthed or ungrounded systems the positive as well as the negative poles of the strings require fused overcurrent protection. Functional earthing fuses may be used according IEC 60364-7-712:2002 [6]

PV array and sub-array fuses must be installed. Tripping of fuses is difficult to detect and leads to loss of generated power. It is recommended to use fuse monitoring to ensure easy identification of fuse operation and repair of the damaged device.

Safe fuse link replacement is ensured by using fuse-switch combination units Fuse monitoring can be included in these units.

The rated breaking capacity of the gPV fuse installed must be equal or exceed the maximum short circuit current of the system. Special care for sufficient breaking capacity has to be taken in big installations, where also other sources (grid, batteries, etc.) can feed the short circuit.

The rated voltage of the fuse should be selected according to

$$U_n \geq 1{,}2 \cdot V_{OC,STC}$$

Where $V_{OC,STC}$ is the maximum open circuit voltage of the PV array , see Figure 1. The factor 1,2 is used to take into account lower temperatures, see Figure 1, covering temperature down to -25°C. For lower temperatures contact the module manufacturer.

For the definition of the rated current of the fuse link used we have to differentiate between

- gPV string fuse
- gPV (sub) array fuse
- rated current of cables

For gPV string fuses the formula

$$I_n \leq I_{MOD,REVERSE}$$

is used and ensures, that the reverse current withstand capability of the module is not exceeded.

IEC 60364 -7-712 [6] gives the following guideline to assign the rated current of the string fuse link

$$1{,}5 \cdot I_{SC,MOD} \leq I_n \leq 2{,}4 \cdot I_{SC,MOD}$$

and for PV array and sub-array fuses

$$1{,}25 \cdot I_{SC,S\_ARRAY} \leq I_n \leq 2{,}4 \cdot I_{SC,S\_ARRAY}$$

$I_{SC\ MOD}$: the short circuit current of a PV module or PV string at Standard Test Conditions (STC), as specified by the manufacturer in the product specification plate. As PV strings are a group of PV modules connected in series, the short circuit current of a string is equal to $I_{SC\ MOD}$

$I_{SC\ S\text{-}ARRAY}$: the short circuit current of a PV sub-array at Standard Test Conditions (STC), and equal to $I_{SC\ S\text{-}ARRAY} = I_{SC\ MOD} \times S_{SA}$, where S_{SA} is the number of parallel-connected PV strings in the PV sub-array

Furthermore the rated current of the cables must exceed the rated current of any series fuse-link.

Protection of windmills

The overload and short circuit protection of the electric system in windmills is very specific as the can be in very different parts of the windmill, such as

- Control of pitch of rotor
- Control of nacelle direction
- Protection of semiconductors in the rectifier and inverter
- Protection of control equipment
- Protection of output transformer or grid link components

As technology of wind mills still is in a rapid process, the voltages vary greatly within the system. In many cases 690V a.c. operating voltage within generator is used.

Many of the different applications within a windmill are already covered (e.g. cable protection, semiconductor protection). In any case a derating is normally needed to cover a wide range of temperatures and/ or vibration requirements and/or salt atmospheres. In many cases these requirements are outside the present standard and often very specific.

Therefore the fuse manufacturer should be consulted for the selection of a proper, maybe special fuse.

Summary

The input into the edition 2.0 of IEC 60269-5 has clarified and added information some important applications of fuses, such as photovoltaic and wind energy as well as use in high altitudes and other relevant subjects mentioned. SC 32B hopes that this guide will be used for information of the user and quoting purposes and gets a wide knowledge not only in the fuse community, but also to all users of fuses and to design engineers to support the use of fuses.

Literature and sources

- [1] IEC/TR 60 269-5, Ed.2.0¸2014-03: Low-voltage fuses Part 5: Guidance for the application of low-voltage fuses
- [2] IEC 121A/42/FDIS, 2015-03-06: Amendment 2 to IEC 60947-3 Ed. 3: Low voltage switchgear and controlgear-Part 3: Switches, disconnectors, switch disconnectors and fuse-combination units
- [3] IEC 60 269-2, Ed.5.0, 2013-07: Low-voltage fuses – Part 2: Supplementary requirements for fuses for use by authorized persons (fuses mainly for industrial application) – Examples of standardized systems of fuses A to K
- [4] IEC 60 269-4, Edition 5.1, 2012-05: Low-voltage fuses – Part 4: Supplementary requirements for fuse-links for the protection of semiconductor devices
- [5] IEC 60 269-6, Edition 1.0 2010-09: Low-voltage fuses – Part 6: Supplementary requirements for fuse-links for the protection of solar photovoltaic energy systems
- [6] IEC 60364-7-712:2002: Electrical installations of buildings Part 7-712: Requirements for special installations or locations –Solar photovoltaic (PV) power supply systems

Tables, Diagrams, Figures

Note: All tables are from IEC 60269-5

Table 1 – Derating factors for different altitudes

Altitude *h* in m	Derating factor *I*/*I*n
2 000	1,000
2 500	0,975
3 000	0,950
3 500	0,925
4 000	0,900
4 500	0,875
5 000	0,850

Table 2: Definition and symbols of switches and fuse-combination units

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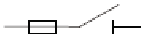
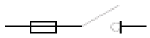
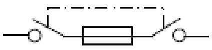
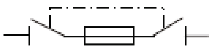
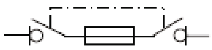
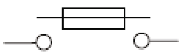
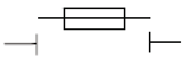
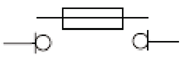
Functions		
Making and breaking current	**Isolating**	**Making, breaking and isolating**
Switch 	Disconnector 	Switch-disconnector 
Fuse-combination units		
Switch-fuse single break  a	Disconnector-fuse single break[b]  a	Switch-disconnector-fuse single break[b]  a
Switch-fuse double break 	Disconnector-fuse double break[b] 	Switch-disconnector-fuse double break[b] 
Fuse-switch single break 	Fuse-disconnector single break[b] 	Fuse-switch-disconnector single break[b] 
Fuse-switch double break 	Fuse-disconnector double break[b] 	Fuse-switch-disconnector double break[b] 

Table 3: Maximum operational voltage ratings of a.c. fuse links

Table 4 – Maximum operational voltage of a.c. fuse-links

Utilization category	Rated voltage V a.c.	Maximum operational voltage V a.c.
gG, gM, aR [a, b], aM, gR [a, b], gS [a, b], gU, gK	230	253
	400	440
	500	550
	690	725
	1000	1100
gN[a], gD[a]	600	600

Table 5 – Typical operational voltage ratings of d.c. fuse-links

Utilization category	Typical rated d.c. voltage	Typical maximum d.c. operational voltage	Time constant
gG, gM, gU, gK	up to 500 V	+10 % over marked rating	15 to 20 ms
gN, gD	up to 500 V	+0 % over marked rating [a]	10 to 15 ms
aR, gR, gS	up to 1 500 V [b]	+5 % over marked rating [a]	15 to 20 ms
VSI (inverter rating)	up to 1 500 V [b]	+10 % over marked rating [a]	1 to 3 ms
gPV	up to 1 500 V [b]	+0 % over marked rating [a]	1 to 3 ms

Diagram 1: Examples of time/current characteristics gK

Note: Diagram 1 is from IEC 60269-2

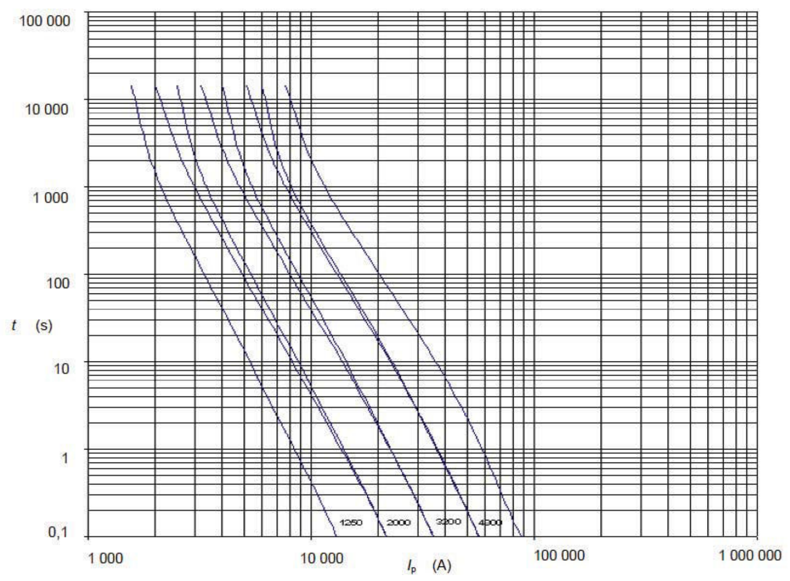
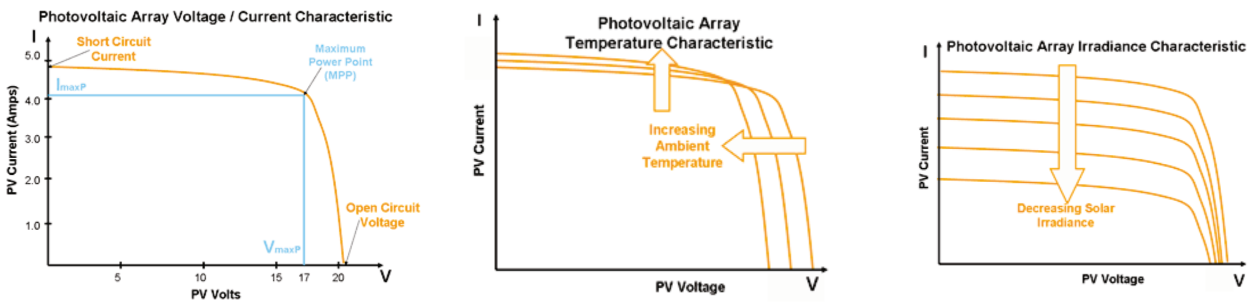


Figure 1: characteristics of PV Systems

abgerufen am 02.08.2015 http://www.mpoweruk.com/solar_power.htm



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