Technical Series, Edition 14

Influences of Modern Technology on Harmonics in the Distribution Grid

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1. Quality of supply

The quality of supply in electric grids is determined by three factors:

Supply quality
=
voltage quality + availability + service quality

Technological advancement of power consumers and generators considerably influenced the supply quality in low-voltage distribution grids over the last 10 to 20 years. At the same time, equipment susceptibility to interferences of voltage quality is increasing. EN 50160 describes the following main characteristics of the supply voltage at connections to public grids:

- Voltage magnitude, slow voltage changes
- Fast voltage changes, flicker
- Voltage dips
- Supply interruptions
- Voltage unbalance
- Harmonic voltage and interharmonic component
- Line-frequency and transient overvoltages
- Frequency variations

Tab. 1 lists permissible voltage levels for the electric supply grid according to EN 50160 and gives value pairs for guidance. A simple matrix of voltage quality issues with regard to causes and consequences can be found in chapter 5 of [1]. The voltage quality is determined by the required power quality of the supply and distribution grid configuration and by harmonic distortions which are fed into the distribution grid by consumers and distributed power generators connected into supply. Instruments such as SICAM Q80 or SENTRON 7KM PAC3200/4200 can be used to measure the power quality. Since basically all users in the distribution grid are affected by voltage quality problems, and as operational changes can always take place, planning should already consider suitable instrumentation. For the future it can be expected that the voltage quality will be a criterion for recourse claims or price changes, and that it lies with the operator's responsibility to provide evidence thereof.

As the power generation concept is currently being rewritten – away from load-managed power stations close to the load centre and towards distributed power supply, which is weather- and time-dependent and subject to local conditions – intelligent concepts such as the "Smart Grid" are called for. The efficient use of instrumentation and automation, storage technology and energy consumption control as well as controllable energy conversion technologies – such as frequency converters for motor drives, uninterruptible power supply systems, switched-mode power supply units and charging stations for electric vehicles – must be considered by the planning engineer.

Tab. 1: **Voltage characteristics of electricity supplied by public grids in accordance with EN 50160**

Characteristic	Requirements	Measurement interval	Period under consideration
System frequency	Interconnected grid: 50 Hz +4% / –6% continuous; 50 Hz ± 1% during ≥ 99.5% of a year Isolated operation: 50 Hz ± 15% continuous; 50 Hz ± 2% during ≥ 95% of a week	10-s average	1 year 1 week
Slow voltage changes	U_n +10% / –15% continuous U_n ± 10% during ≥ 95% of one week	10-min average	1 week
Flicker / fast voltage changes	Long-term flicker severity $P_{lt} < 1$ during ≥ 95% of a week and $\Delta U_{10ms} < 2\%\ U_{rated}$	2 h (flickermeter in acc. with IEC 61000-4-15; VDE 0847-4-15)	1 week
Voltage unbalance	U (negative phase-sequence system) / U (positive phase-sequence system) < 2% during ≥ 95% of a week	10-min average	1 week
Harmonics U_{n2} … U_{n25}	< limit value in acc. with EN 50160 and THD < 8% during > 95% of a week	10-min average of each harmonic	1 week
Subharmonics	being discussed		1 week
Signal voltages	< standard characteristic curve = $f(f)$ during ≥ 99% of a day	3-s average	1 day
Voltage dips	Number of < 10 … 1,000 / year; of which > 50% with t < 1 s and $\Delta U_{10ms} < 60\%\ U_n$	10-ms r.m.s. value U_{10ms} = 1 … 90% U_n	1 year
Short voltage interruptions	Number of < 10 … 1,000 / year; thereof > 70% with a duration of < 1 s	10-ms r.m.s. value $U_{10ms} \geq 1\%\ U_n$	1 year
Long voltage interruptions	Number of < 10 … 50 / year; thereof > 70% with a duration of < 3 min		1 year
Temporary overvoltage (L-N)	Number of < 10 … 1,000 / year; thereof > 70% with a duration of < 1 s	10-ms r.m.s. value $U_{10ms} \geq 110\%\ U_n$	1 year
Transient overvoltage	< 6 kV; µs … ms		n.s.

It is the growing use of

- non-linear loads such as lamp ballasts, dimmers, and power supply units with semiconductor rectifiers,
- converters with power electronics such as diodes, thyristors and transistors in frequency converters, battery chargers, and UPS devices,
- inverters for line feed-in as they are used in photovoltaic systems and wind turbines,

and the on/off-switching effects in power consumers which increasingly generate harmonics in the distribution grid and thus harmonic distortions in the supply grid. The periodical switching of semiconductor components creates harmonic currents which – as a function of the line impedance – cause harmonic voltages to be superimposed over the voltage fundamental. For details as well as for permissible levels of harmonic content and the total harmonic distortion THD_U of the supply voltage in accordance with EN 50160 (THD_I is the total harmonic distortion for the current), please consult the Planning Manual [1] (section 5.1.2.). Fig. 1 exemplifies, how harmonics distort the sinusoidal progression of the 50-Hz fundamental.

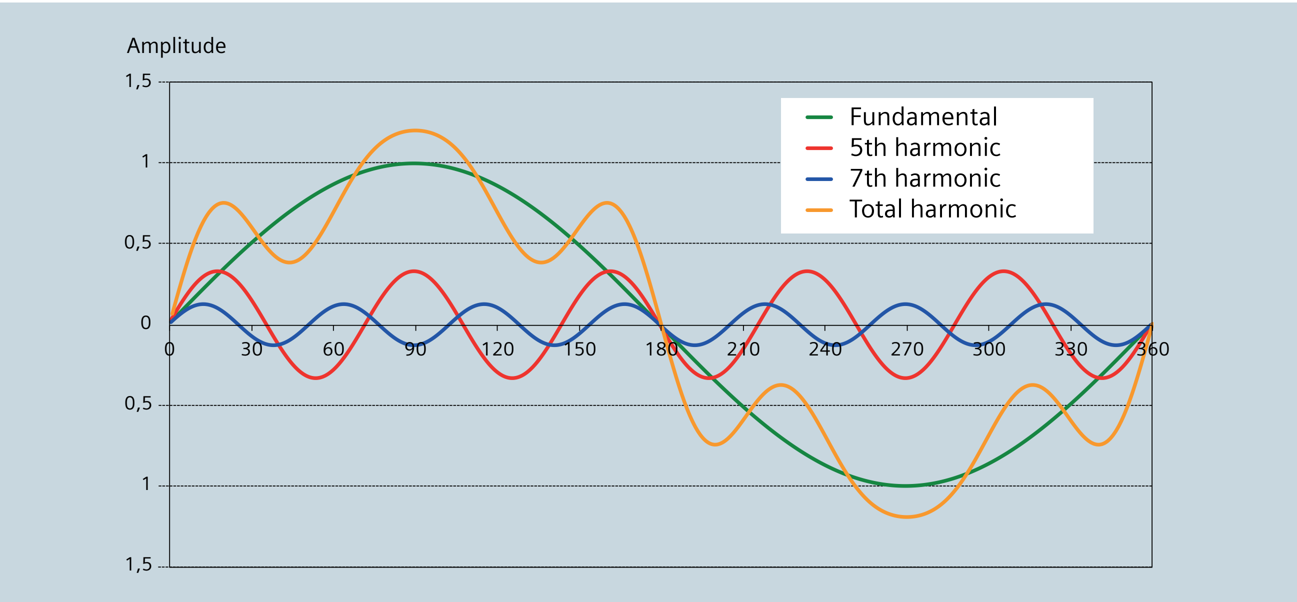


Fig. 1: **Impact of harmonics on a sinusoidal fundamental**

$$THD_U = \frac{\sqrt{\sum_{\nu=2}^{40} U_\nu^2}}{U_1} \qquad THD_I = \frac{\sqrt{\sum_{\nu=2}^{40} I_\nu^2}}{I_1}$$

The values of the individual harmonic currents of loads and converters should be specified in the equipment datasheets or must be requested from the manufacturer. Please note that common terminology refers to the fundamental as first harmonic (or harmonic of the first order). This means, the frequency of the n-th harmonic is:

n = 1: f_1 = 1 ∗ 50 Hz = 50 Hz (fundamental)

n = 2: f_2 = 2 * 50 Hz = 100 Hz (2nd harmonic)

n = 3: f_3 = 3 ∗ 50 Hz = 150 Hz (3rd harmonic)

n = 4: f_4 = 4 ∗ 50 Hz = 200 Hz (4th harmonic)

n = 5: f_5 = 5 ∗ 50 Hz = 250 Hz (5th harmonic)

A vector representation of the 3-phase system allows to dissect every load curve – in respect of its transformation into different coordinate systems – into a

- system rotating with the fundamental (co-rotating components n = 3∗k+1),
- system in anti-clockwise rotation of the fundamental (anti-clockwise rotating components n = 3∗k+2)
- stationary system (zero-components n = 3∗k) (see Tab. 2).

This clearly illustrates, that non-linear loads and harmonic generators

- may additionally heat up conductors, coils, and transformers and may also cause the neutral conductor to be overloaded, since the zero-components of the harmonic result in currents in the zero phase-sequence system which add up in the neutral,
- may result in a braking rotary field and a lower torque in rotating machines if components of the negative phase-sequence system are being created,
- may result in unwanted acceleration and a higher motor torque, if additional components are generated in the positive phase-sequence system by harmonics.

Tab. 2: **Dissection of harmonics into rotating reference systems (+ 50 Hz; 0; - 50 Hz)**

Harmonic	1	2	3	4	5	6	7	8	9	10	11
Frequency in Hz	50	100	150	200	250	300	350	400	450	500	550
Signs	+	-h	0	+	-h	0	+	-h	0	+	-
Order of harmonic	h=3k+1	h=3k-1	h=3k	h=3k+1	h=3k-1	h=3k	h=3k+1	h=3k-1	h=3k	h=3k+1	h=3k-1

Signs	Rotation	Consequences
Positive (+)	Forward (positive phase-sequence system)	Heating of conductors and protection relays
Negative (-)	Reverse (negative phase-sequence system)	Heating of conductors and protection relays + motor trouble
Zero (0)	None (zero phase-sequence system)	Addition of currents and heating in the neutral

k = 1, 2, 3, ...

If there are no generators of harmonics in an electric power distribution system, apparent power is only required for the fundamental (S_1). For 3-phase AC current, it is determined from the active power ($P_1 = P$) and the reactive power for the fundamental (Q_1) and the factor cos φ (fundamental):

$$P = P_1 = U \cdot I_1 \cdot \cos\varphi$$
$$Q_1 = U \cdot I_1 \cdot \sin\varphi$$
$$S_1 = \sqrt{P_1^2 + Q_1^2}$$

Harmonic reactive power D, also called distorted reactive power, is produced due to the requirements of non-linear electrical assemblies:

$$D = U \cdot \sqrt{\sum_{\nu=2}^{\infty} I_\nu^2}$$

The total apparent power is calculated as follows:

$$S = \sqrt{P_1^2 + Q_1^2 + D^2}$$

The power factor λ is defined as the ratio of active power P ($= P_1$) and apparent power S:

$$\lambda = \frac{P}{S} \qquad \cos\varphi = \frac{P}{S_1}$$

Without distorted reactive power factoring in:

$S = S_1$ and thus $\lambda = \cos\varphi$

Even if the fundamental reactive power is fully compensated ($\cos\varphi = 1$), distorted reactive power, and hence reactive power, can be a requirement in the power system. Accordingly the power factor λ can be less than cos φ (Fig. 2).

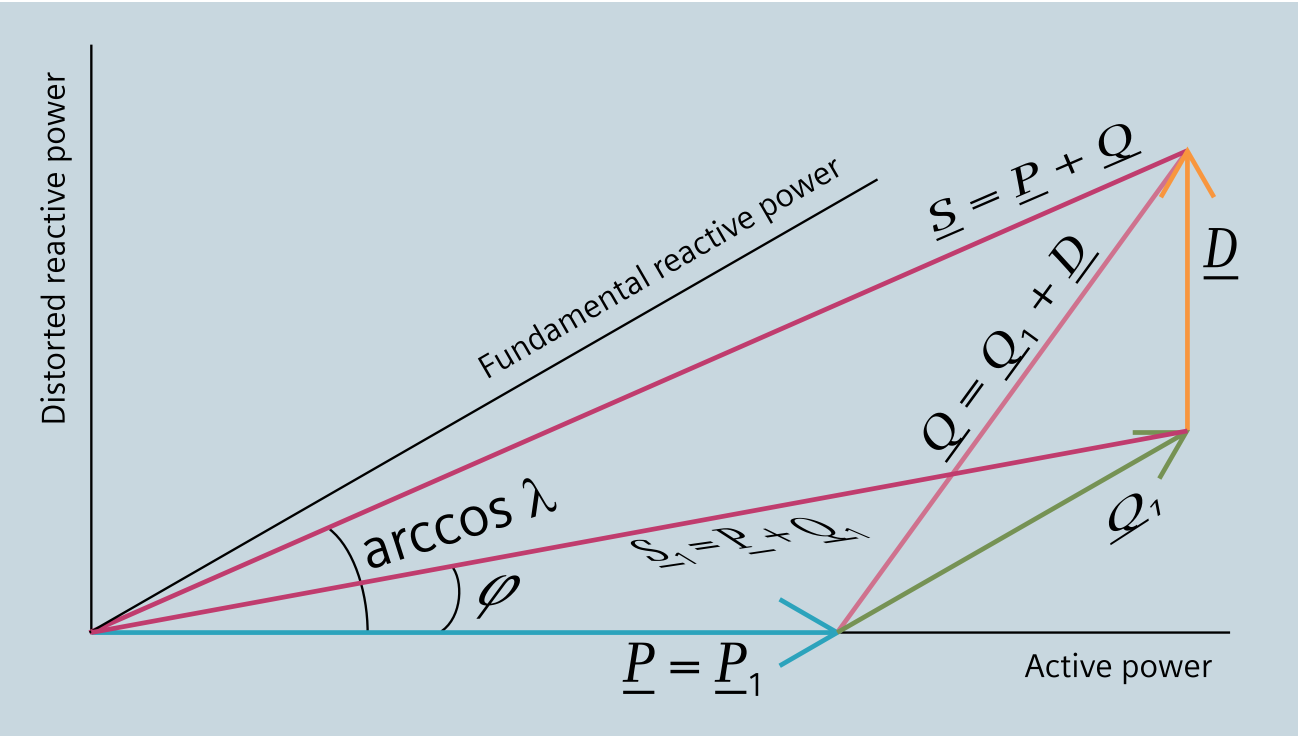


Fig. 2: **Vector representation of active power P_1, reactive power Q_1 for the fundamental, and D for the distorted reactive power as well as the apparent power S and S_1 for the fundamental**

(Note: In the diagram, vectors are marked by underlining; here it is a vectorial addition, not an arithmetic addition.)

It is not only power consumers which make for harmonics by way of non-linear power consumption, but also power generators which feed electricity into the distribution grid through inverters, for example. However, the effects of harmonic generators cannot be established from the knowledge about all the different kinds of generators alone. In fact, the power supply system, the distribution transformer, and, in case of a safety power supply system a standby generating set in isolated operation, must be included in an overall analysis (Fig. 3). Further approaches in this direction can be found in the Planning Manual [1] or in the "Technical Rules for the Assessment of Network Disturbances" [2].

The short-circuit power of the power generators (generator of the standby generating set and photovoltaic system) is often significantly lower in isolated operation than that of supply from the normal power supply grid, so that the line impedance is then increased. Thus, voltage distortion is also increased during isolated operation in case of an identical harmonic current component, and, even if the EN 50160 requirement of $THD_U < 8\%$ is observed during normal operation, this is not necessarily ensured for isolated operation. Accordingly, equipment and consumers are more severely stressed and in certain circumstances their functionality is even at risk.

Moreover, neutral loading must not be neglected. In case of an asymmetrical distribution of 1-phase loads to the phase conductors, residual currents between the phase conductors flow back to the neutral. And the currents of the zero phase-sequence system are added (Tab. 3). These harmonic currents of the phase conductors of an integer frequency which can be divided by 3 (150, 300, 450 Hz, ...) add up in the neutral.

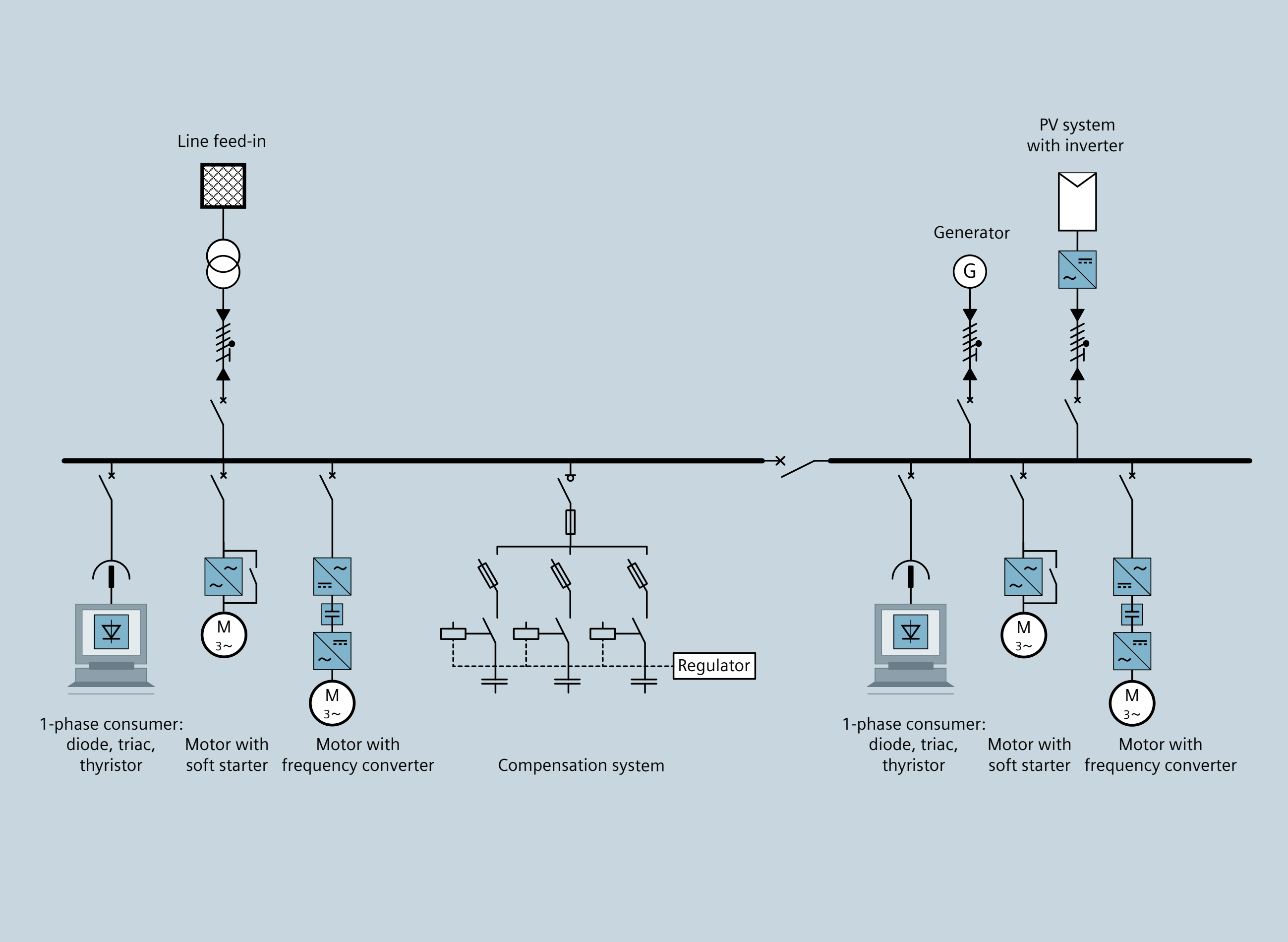


Fig. 3: **Distribution grid with non-linear loads, supplied from a distribution transformer and photovoltaic system or a standby generating set and photovoltaic system in isolated operation**

4. Harmonic response of some components in the distribution grid

Below, some components in the distribution grid are exemplarily discussed with regard to their response to non-linear conditions. As regards transformers and generators, such harmonic distortions must be considered in their rating. Harmonic distortion can be influenced by the selection of non-linear power consumers and in particular semiconductor circuits.

4.1 Transformers

Transformers are rated according to their maximally assumed load. The loading must be symmetrically divided between the phase conductors, so that no or only very low residual currents can flow through the neutral conductor. Normally, the transformer neutral can only be loaded with maximally 100% of the transformer's nominal current. With power converter transformers [1], the current carrying capacity is raised to up to 150%. If higher capacities are required, the transformer can also be oversized.

Harmonics cause additional no-load loss in transformers (magnetic stray current loss and eddy current loss in the iron core) as well as load loss (eddy current loss in the copper windings). Additional loss means additional heating and thus a shortening of the working life for the transformer insulation.

According to IEC 60076-1 (VDE 0532-76-1), normal operating conditions for power transformers with regard to their harmonic content are:

- THD_U and THD_I each less than or equal to 5% of the rated quantity
- Total harmonic content for even harmonics less than or equal to 1%

If the total harmonic content of the full-load current is less than 5%, no significant shortening of its working life needs to be expected. However, its rated overtemperature (in accordance with IEC 60076-2 and -11 and VDE 0532-76-2 and -11 respectively) may be reached. In that case, additional cooling, for example by way of additionally mounted fans (cross-flow fans), should be considered. If THD_I exceeds 5%, a power converter transformer can be used (in accordance with IEC 61378). Currently, such power converter transformers are mainly used in industrial applications.

Alternatively, transformers can be oversized. At the same time, this helps curb the effects of harmonic currents in the distribution grid:

- Transformer with a greater apparent power rating
- Transformer with a lower relative short-circuit voltage rating
- Additional parallel transformer to extend an existing plant

These measures result in higher short-circuit currents which in turn have repercussions on the selection of switching and protective devices, as well as cables/cords and busbar trunking systems. Selectivity between the protective devices must be re-evaluated.

The increased rated apparent power of transformers also has an effect on the thermal current loss. In a loss comparison, no-load loss and load loss must be added up. Load loss rises in square as a function of increasing load, whereas the no-load loss remains unchanged. Therefore, when seeking the loss-oriented operational optimum, no-load loss and load loss in dependency of the load curve must be considered (see [1] section 14.2). The overall economic evaluation must consider cost of investment and service/maintenance. Relevant calculations can be performed by the Siemens TIP Consultant Support.

4.2 Generators

In case of a power outage, generators continually supply those consumers connected to a safety power supply system (SPS) and additionally, in some cases, even some selected consumers within the normal power supply (NPS). In such a situation, the operational conditions for SPS operation must be adhered to. Typical requirements placed on a power source for safety supply are specified in IEC 60364-5-56 (VDE 0100-560) and detailed in location-specific standards, such as IEC 60364-7-705 (VDE 0100-705) for agricultural and horticultural premises, IEC 60364-7-710 (VDE 0100-710) for medical locations and IEC 60364-7-718 (VDE 0100-718) for communal facilities and workplaces.

Generators can also be used for load management, for example to reduce peak load and thus the demand charge portion of the average electricity price (see [1] section 14.5). Distribution system operators are increasingly offering operators of standby power generating sets more favourable conditions if the latter use their generators to cover short-time load peaks and thus back up the power system of the distribution system operator.

With 8 to 14%, the typical subtransient reactance of a generator is usually significantly higher than the rated short-circuit voltage u_{kr} of a transformer. For this reason, voltage distortions originating from non-linear conditions will be greater in isolated operation of the generator than during normal DSO supply. Moreover, generator performance often greatly depends on the power factor λ. Fig. 4 shows a typical Heyland diagram, from which it becomes clear that a consumer network with capacitive loads may require severe power reductions for the generator.

If many computers in an office tower are operated with simple power supply units (capacitors for power factor correction) in an SPS, for example, it may happen in isolated generator operation that the generator is not sufficient to take the required capacitive load.

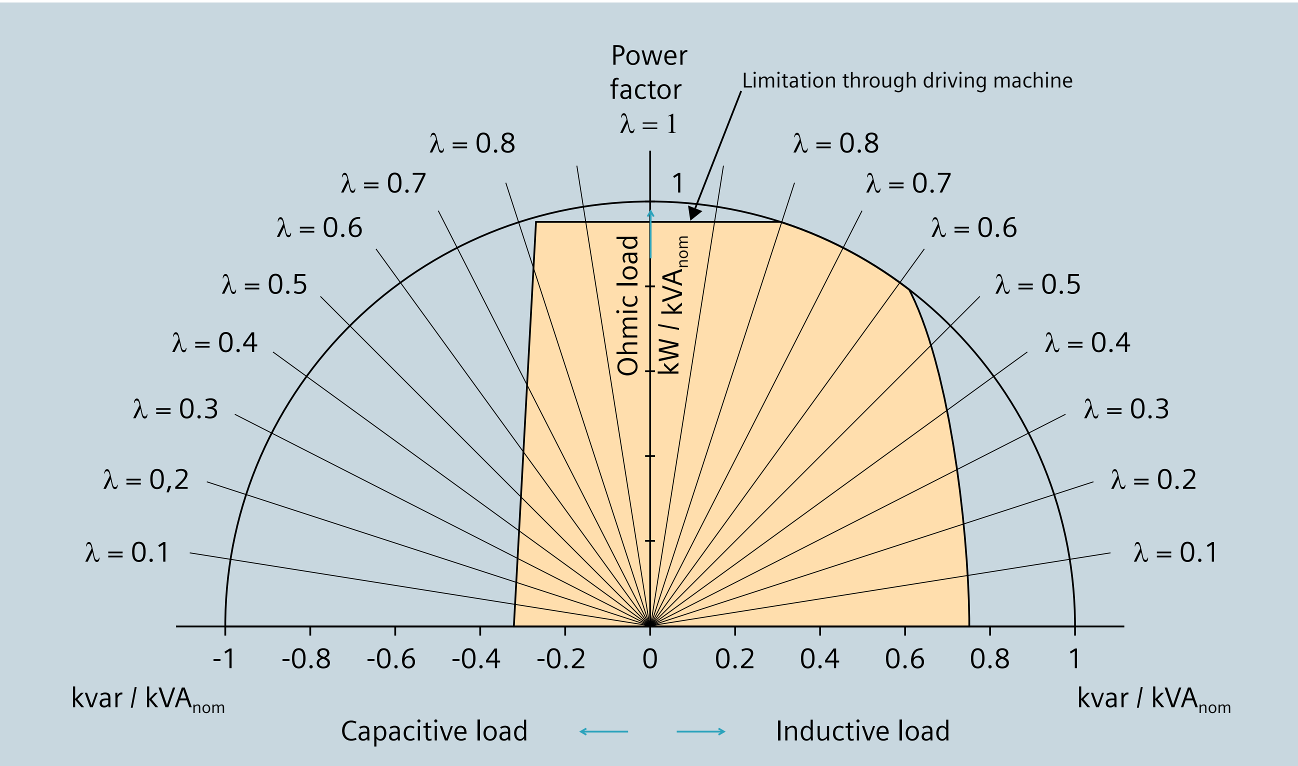


Fig. 4: **Example of a generator load curve as Heyland diagram**

4.3 1-phase electronic devices

Typical examples of 1-phase devices or device combinations which generate harmonics are:

- Power supply units with an uncontrolled diode rectifier
- Fluorescent lamps with conventional or low-loss ballasts and their inductances
- Dimmers with gate-controlled thyristors or triacs whose phase angle control results in such disturbances

For a typical 1-phase rectifier circuit with a non-controlled 2-pulse bridge B2 there is a theoretical harmonics spectrum as shown in Fig. 5.

Harmonic currents of the zero phase-sequence system (3rd, 6th, 9th, ..., 3∗n-th order) add up arithmetically in the neutral and may cause a very high neutral current in case of a very asymmetrical phase loading.

As lighting systems, and also electronic equipment, are only turned on and off or regulated for their actual period of use for reasons of efficiency, it makes sense to reduce harmonics for every single power consumer. Power supply units with passive power factor correction (PFC) by means of a reactor are mostly used for small wattages up to about 200 W. Power factor correction can be substantially improved, typically up to a best value of about $\lambda \approx 0.98$, by means of active PFC using a so-called "upward current transformer" which uses gate-controlled semiconductor components.

High-frequency interferences are superimposed on the distribution grid by switching frequencies of active components in the range of 10 kHz and much more. Especially when many such components are used, for example electronic ballasts (EB) for compact fluorescent lamps, high-frequency interferences seem to make trouble.

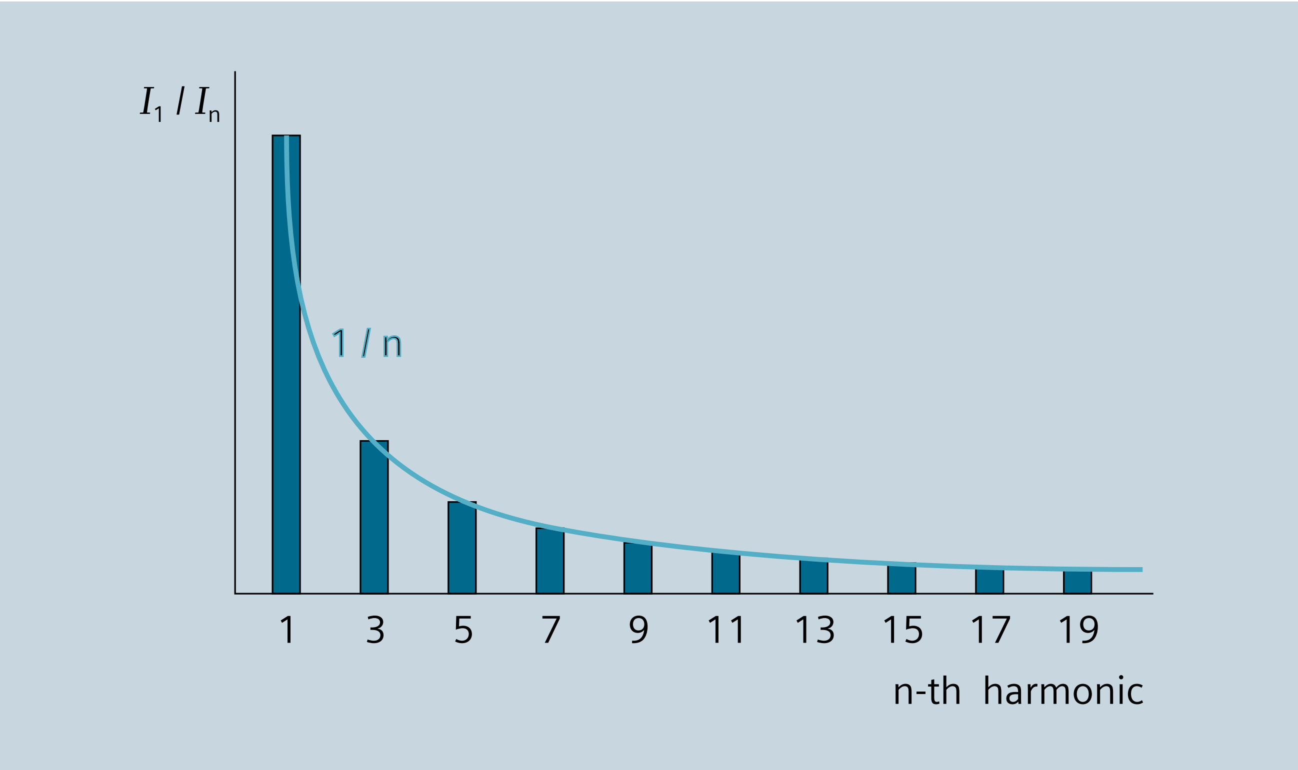


Fig. 5: **Harmonics spectrum for a B2 bridge circuit**

4.4 3-phase current inverters for soft starting and frequency converters for motor operation

3-phase current bridge circuits or 3-phase midpoint circuits are normally suitable both for soft starting 3-phase motors and frequent motor speed control at an optimal torque, but they bring about harmonics. Some typical semiconductor circuits have proven helpful to fulfil different tasks.

For soft starting, the motor shall be steplessly run up to operating voltage according to the desired torque starting curve. The typical method is phase angle control of a gate-controlled thyristor bridge circuit of a soft starter (Fig. 6), until the operating voltage has been reached. Then it is switched to the bypass, so that no more loss occurs through the bridge circuit and harmonics are no longer present either.

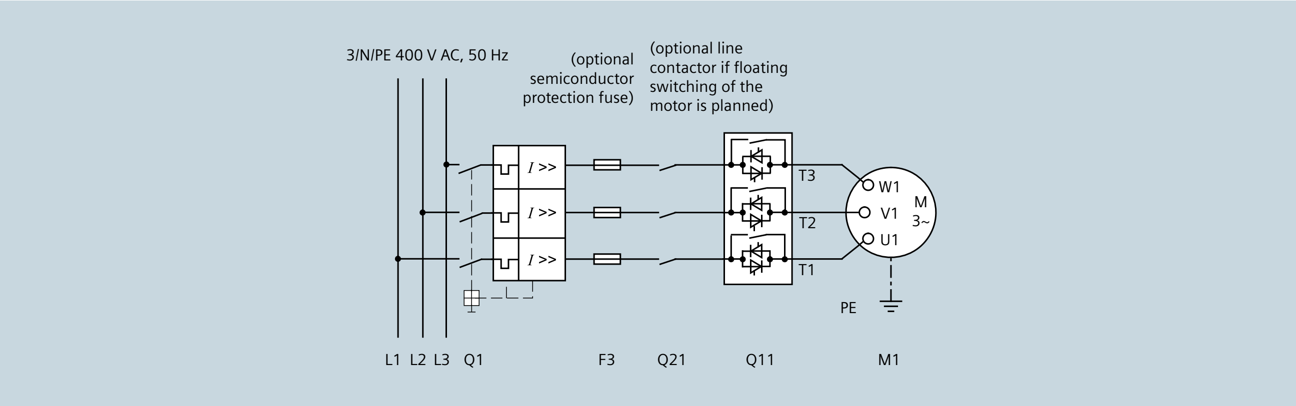


Fig. 6: **Simplified circuit diagram of a SIRIUS 3RW44 soft starter**

With frequency converters, the method is a double conversion: from the line AC voltage to the DC link voltage and then back to the driving AC voltage for the motor. There are great differences in rectifier use. A non-controlled B6 diode bridge with electrolytic capacitors in the DC link generate current harmonics of the 5th, 7th, 11th,13th, 17th, 19th, ..., n-th order – meaning uneven harmonic currents which cannot be divided by 3. When the rectifier uses gate-controlled thyristors, network load is created owing to commutation dips which corresponds to the switching gaps in the sinusoidal current progression. Measures how to curb network load by means of filters, transformers, increasing the pulse number for the bridge circuit, or by using IGBTs instead of diodes and thyristors will be briefly described in chapter 5.

In addition, high-frequency interference is emitted in the frequency converter caused by the rapidly switching IGBT inverters. These interference currents may cause noise and additional heating of the motor. The high-frequency leakage currents must flow back to earth through the capacities of the motors cable and the motor winding and in a suitable manner back to its source, the inverter. Without filters in the converter, which offer these high-frequency interference currents a suitable low-ohmic way back to the inverter, all these interference currents would have to go through the line-side PE connection of the converter to the transformer neutral and from there further on through the 3-phase network back to the converter. On this way they would superimpose the line voltage with high-frequency interference voltages and thus disturb all consumers which are connected to the same point of common coupling (PCC, see Fig. 7).

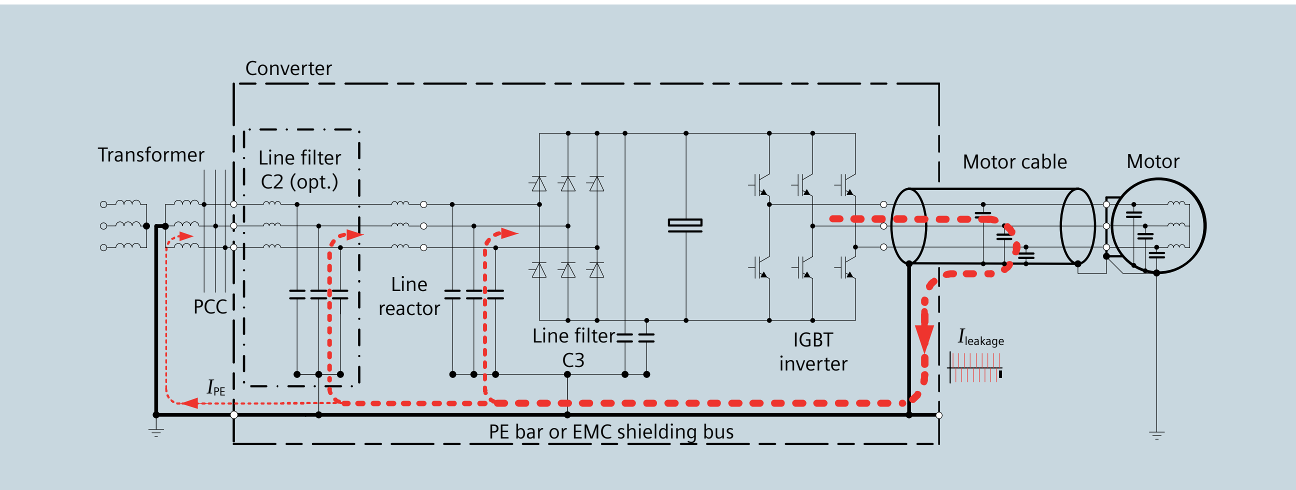
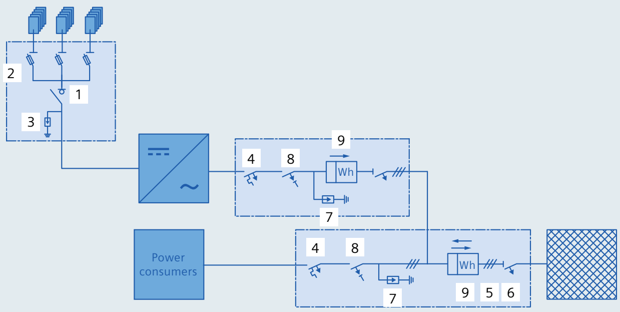


Fig. 7: **Filtering of leakage currents in the frequency converter**

4.5 Photovoltaics inverters

Similar to soft starters and frequency converters, there is a wide range of different circuit types for PV inverters, which are also called solar inverters. There are 1-phase and 3-phase inverters, line-commutated and self-commutated ones, with thyristors and transistors, with and without boost converters, with and without 50 Hz- or HF-transformer and with many more distinguishing features, such as filters and power factor correction. The harmonic spectra of the plants vary accordingly, since the feed-in power may also greatly vary. In addition to the generally relevant standards for this field of application which must always be observed, line-parallel connection of a PV system is subject to standards such as IEC 60364-7-712 (VDE 0100-712), IEC 60269-6 (VDE 0636-6), IEC 62109-1 and -2 (VDE 0126-14-1 und -2), the IEC 61000 series (VDE 0838) and the German VDE guideline VDE-AR-N 4105. When connecting PV modules, it must therefore be ensured that they be separated at the AC side and the DC side, for example, and that overvoltage protection is provided. If applicable, a residual current device (RCD) of class B or B+ must be used (see section 11.2 in [1]) (Fig. 8).



1	5TE2 DC isolator
2	3NW PV cylinder fuse system
3	5SD7 overvoltage protection device (DC)
4	5SL/5SY miniature circuit breaker (AC)
5	SHU 5SP3 main miniature circuit breaker
6	NEOZED 5SG7/5SE fuse system
7	5SD7 overvoltage protection device (AC)
8	5SM3 residual current circuit breaker
9	7KT PAC1500 measuring instrument

Fig. 8: **Connection of a photovoltaic system to the distribution grid**

An existing facility with a PV system and generator can be expanded by a self-contained storage system comprising, for example, a battery system and a self-commutated 4-quadrant inverter in the charging/discharging unit, in order to enable optimal utilisation of solar energy both in isolated operation and in normal power supply mode (Fig. 9).

IEC 62109-2 (VDE 0126-14-2) specifies a maximum permissible THD_U of 10% for an inverter with a sinusoidal output voltage for isolated operation and the different harmonic levels must not exceed 6%. For an inverter with a non-sinusoidal output voltage, the overall THD_U value must not exceed 40%. All specifications and data of EN 50160 apply to normal power supply system operation.

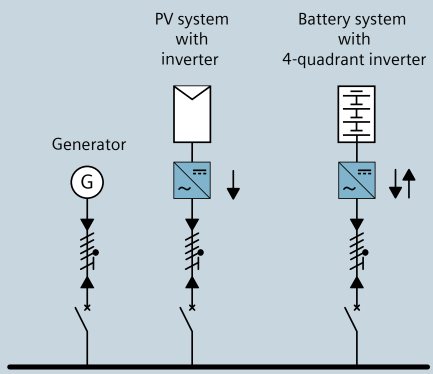


Fig. 9: **Power supply in the isolated network with generator, PV system, and battery storage system**

4.6 Cables/cords

Network dimensioning establishes the cable cross sections corresponding to the required current carrying capacities of the cables, in order to determine the required protection of cables and cords against overload. To this end, the specifications made in the German DIN VDE 0298-4 standard are used to account for the installation methods and ambient conditions. According to DIN VDE 0298-4, the nominal cross section of the neutral conductor must at least correspond to that of the phase conductors if the THD_I of the harmonic currents is more than 15%. Conductor heating caused by the harmonic currents is taken account of by reduction factors (Tab. 3). Specifications in DIN VDE 0298-4 only apply to symmetrically loaded 3-phase networks without any impact of harmonics.

From Tab. 3 it can be deduced that a current component of approximately 15% already makes neutral current monitoring useful even if IEC 60364-4-43 (VDE 0100-430) remains very general in this respect. Overload monitoring is only required for the neutral conductor if it can be expected that the proportion of harmonics in the phase-conductor current is so high that the current flowing through the neutral will exceed the continuous current carrying capacity of this conductor. At this point, the reader's attention must be called to the fact that a PEN conductor in a TN-C network may be monitored but not switched.

Supplementing DIN VDE 0298-4, Addendum 3 of DIN VDE 0100-520 elaborates on the importance harmonics for cable and cord rating. To do so, the current components of the 3rd harmonic referred to the total current in the phase conductors are divided into categories as given in Tab. 3: > 15 to 33%, > 33 to 45% and > 45%. DIN VDE 0100-520 Addendum 3 also gives an explanation for the correction factors of Tab. 3 (detailed both in DIN VDE 0298-4 and in DIN VDE 0100-520 Addendum 3).

For a precise determination of cable/cord dimensions in dependency of harmonic currents – compared with the correction factors of Tab. 3 – DIN VDE 0100-520 Addendum 3 mentions two procedures.

i) Using an approximation table for the correction factor: In dependency of the proportion of non-linear loads, a correction factor according to Tab. 4 is determined and considered in the current carrying capacities listed in the tables of DIN VDE 298-4.

ii) Estimating the current consumption and distorted cur rents of various power consumers: To this end, a table in DIN VDE 0100-520 Addendum 3 lists the data of some typical 1-phase office equipment (Tab. 5). From it, the phase current and harmonic currents as well as the neutral current can be read for individual consumers. They can be added up. The quotient from the phase conductors' harmonic currents and the phase currents define the proportion of harmonic currents. The percentage load and the neutral load allow to determine the cable/conductor cross sections.

Tab. 3: **Reduction factors for considering the 3rd harmonic currents for rating cables/cords in accordance with DIN VDE 0298-4**

Proportion of 3rd harmonic current in the phase current	Reduction factor	
	Ampacity of phase conductors	Neutral current
0 to 15%	1.0	
> 15 to 33%	0.86	
> 33 to 45%		0.86
> 45%		1.0

Tab. 4: **Conversion factors for considering harmonics-influenced consumers in acc. with DIN VDE 0100-520 Addendum 3**

Proportion of power required	Conversion factor (for distribution circuits)
0 to 15%	1.00
> 15 to 25%	0.95
> 25 to 35%	0.90
> 35 to 45%	0.85
> 45 to 55%	0.80
> 55 to 65%	0.75
> 65 to 75%	0.70
> 75%	0.65

Tab. 5: **Examples of distorted currents for typical office equipment in acc. with DIN VDE 0100-520 Addendum 3**

Electronic equipment	Power consumption P in W	Current input I_{Load} in A	Distorted current I_V in mA
Fluorescent lamp > 25 W with inductive devices without compensation	62	0.60	67
LED lamp (substituting 58 W T8 fluorescent lamp with inductive ballast)	26	0.12	16
120° dimmed incandescent lamp 200 W	38	0.38	220
Office PC (office day) without active PFC	85	0.48	270
Office PC (office day) with active PFC	82	0.38	57
Tube monitor	60	0.38	200
Flat screen 100% brightness	32	0.24	137
Flat screen 20% brightness	22	0.17	97
Laptop 75 W (heavy duty)	24	0.20	115
Fax machine (daily mean value)	22	0.17	83
Office-type multi-function photocopying machine (daily mean value)	103	0.61	144

5. Semiconductor circuits, compensation and filtering

When harmonics cause trouble, it is helpful not to have them generated in the first place. You can take advantage of semiconductor technology, circuitry and control options to influence harmonic distortions. As distortion-free consumers generating little harmonic content cannot be operated all over the power system at all times, the use of passive or active filters can improve the power quality. Distortions caused by harmonics in the distribution grid can either be reduced by increasing the line short-circuit power or by compensation. Increasing line short-circuit power can normally attained by using a bigger or an additional transformer and generator. We will not discuss this option in more detail below. Since harmonic generators can to some extent also be utilised for their compensation and filtering, a distinction between active and passive components shall suffice.

5.1 Passive filtering and compensation of harmonics

Just like the effects of harmonic distortions can be neutralised by cos φ factor correction by means of compensation units, they can be limited by passive filters coordinated to the respective frequency, so-called series resonant circuits (see [1] section 5.4). As it is very difficult to estimate in the planning stage, how much distorted reactive power is required, it is recommended, initially to provide for the spatial conditions to install compensation systems only. Later, when the plant is running, the demand of reactive power can be firmly established and a suitable compensation system featuring passive or even active filters can be installed (see subsection 5.3).

5.2 Semiconductor switch characteristics and their circuiting

As suggested in chapter 4, a variety of semiconductor components and numerous circuit types can be used for current conversion. Characteristic components are diodes, thyristors, and transistors. Their response shall be exemplified by the 3-phase bridge circuit (Fig. 10). Since switching the diode cannot be controlled, its commutation is always a line-commutation. Besides the option to filter harmonic distortions by a line reactor and/or a DC reactor in the DC circuit, a significant reduction of harmonic distortions can also be attained by phase-shifted circuiting of several 6-pulse bridges (12-pulse or 24-pulse bridge circuit).

Thyristors can be turned on or off through their gate voltage (phase angle control) and can, for this reason, be used line-commutated or self-commutated just like transistor circuits. For thyristors also applies that circuiting several bridges results in reducing harmonic distortions.

Transistors can be turned on and off, so that a quasi linear response can be attained. Fig. 10 shows a circuit for 4-quadrant operation. However, when semiconductors are switched, their pulsing produces high-frequency harmonic components in the kilohertz range, which have so far gained little attention when THD_U and THD_I are to be established.

5.3 Active filtering

For active filtering, self-commutated transistors or operational amplifiers are used which require their own voltage supply for control. A great advantage of active filters is their capability to attune to different interference signals. This means that even in complex network configurations and in cases where non-linear consumers are changed or grid feed-in takes place during operation, the filter adjusts to changing conditions in a flexible manner. Harmonic distortions are detected and a signal phase-shifted by 180° is generated, so that both signals overlay and interferences can be reduced. Suitable filters help avoid the situation that a high-frequency interference emitted due to semiconductor pulsing is fed into the grid.

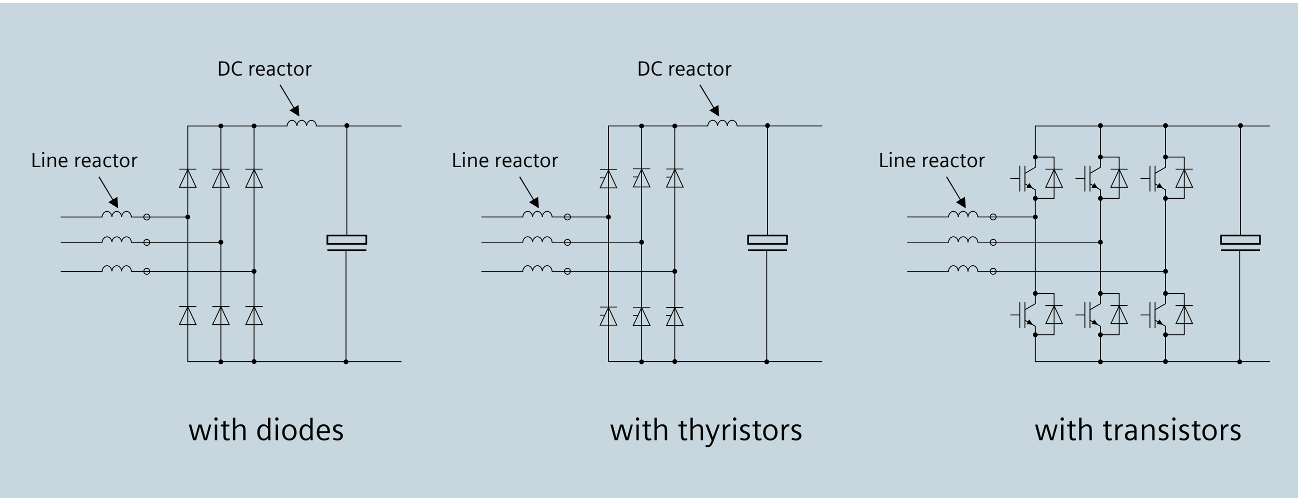


Fig. 10: **Power supply in the isolated network with generator, PV system, and battery storage system**

6. Conclusion

Harmonics are neither a typical characteristic of power generation or power distribution, nor are they an unambiguous product feature. Rather, the assessment of conducted interference caused by harmonics must always encompass a combined analysis of feed-in, grid topology and equipment features. The growing importance of harmonics is considerably boosted by the increased use of power electronics in all fields of application: in frequency converters for motor control, in inverters for photovoltaic systems and wind turbines, for power supply units in electrical appliances and dimmers as well as in inverters for EV charging stations or battery chargers mounted in electric vehicles.

A price-performance-optimized curbing of harmonics is always project-dependent and often specifically tailored to a certain kind of business or plant. Therefore, a future-proof plant assessment should go into the planning considerations. If there is a very great uncertainty as to the harmonic response of preferred power consumers, the operator should be informed about the high cost of active filtering in the case that no influence can be exerted on equipment features or electricity feed-in by the distribution system operator. If harmonics filtering is planned, this should be coordinated with the distribution system operator. Filtering may impair conditions in the upstream grid in certain circumstances.

Please do not hesitate to get in touch with your local contact if you have any questions:
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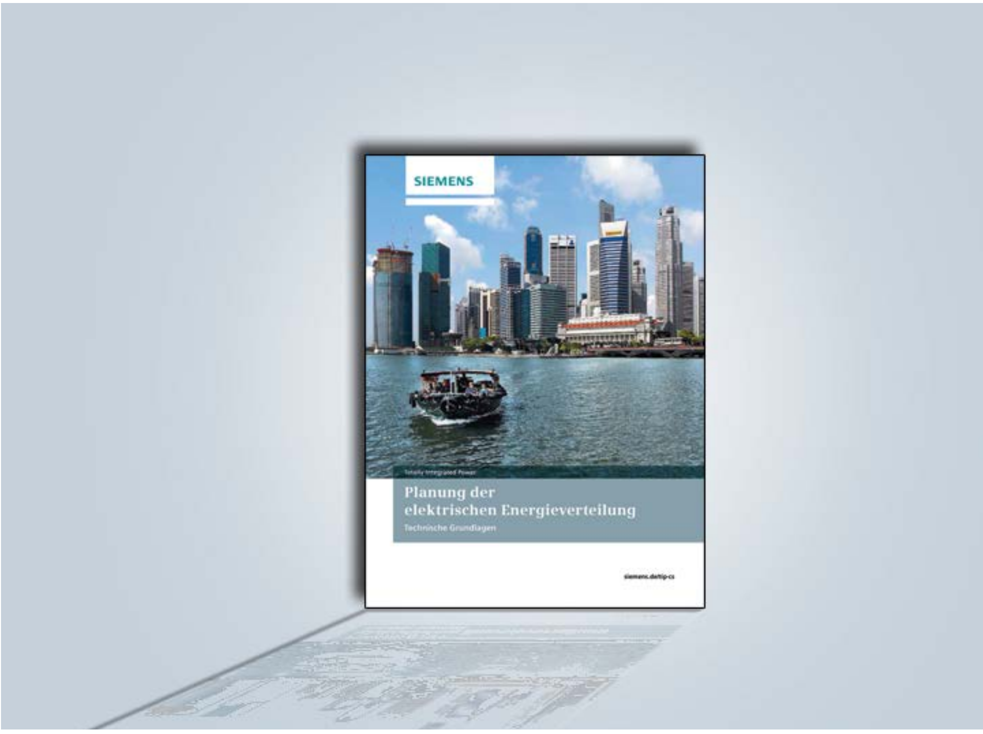

Siemens AG
Energy Management
Medium Voltage & Systems
Mozartstr. 31 c
91052 Erlangen
Germany

E-mail: consultant-support.tip@siemens.com

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