The third harmonic frequency - a guide to the problems and how to solve them

The Third Harmonic Guidebook

THF 80 GB 99-09

ABB Control

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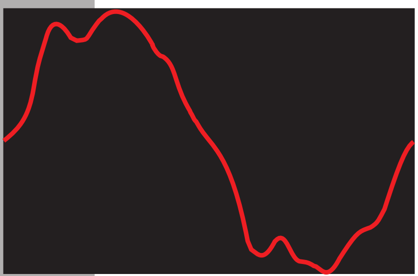
Contents

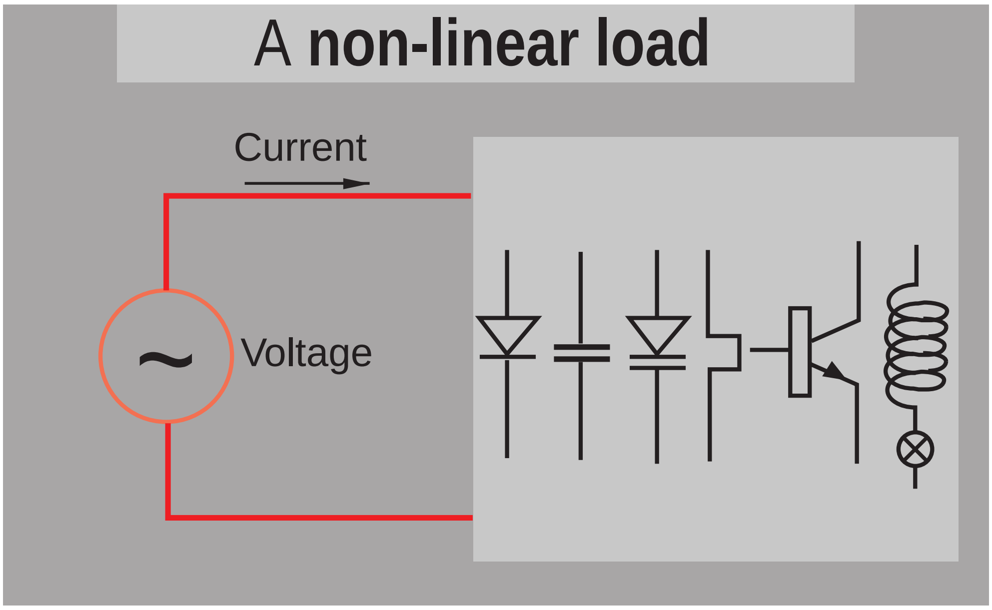
1. Third harmonic frequencies -a growing problem



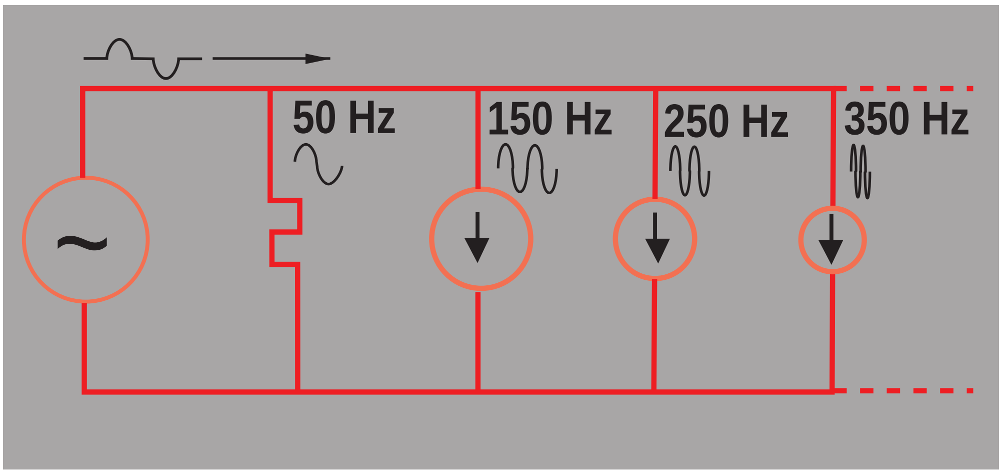
All electrical equipment using alternating current is designed to use a voltage with a clean and regular sine wave. However, in present day networks, this type of curve is extremely rare. Harmonic frequencies create distortions in the sine wave, causing interference to equipment connected to the network.

The harmonics are generated by non-linear loads which are connected to the network. These loads create ripple voltages that generate harmonics at the same frequency. The size of the harmonic current depends on the load and the impedance of the feeding network at the frequency in question. For instance lighting, semiconductor and PC loads generate harmonic voltages and currents of different sizes.

Networks containing small transformers, UPS equipment and emergency power supplies, among other things, are vulnerable to harmonics, and there is a big risk of harmonic currents causing interference to equipment connected to these networks.



Non-linear loads generate harmonics in networks



The most common harmonics which stress networks are the 150 Hz third harmonic, 250 Hz fifth harmonic and the 350 Hz seventh harmonic

The most common harmonics which stress networks are the 150 Hz third harmonic, 250 Hz fifth harmonic and the 350 Hz seventh harmonic. Generally, single-phase loads generate the third harmonic and three-phase loads generate the other harmonics. The fifth and the seventh harmonics can be filtered out by so called "tuned circuits".

Until recently, there was no economic way to filter the third harmonic. Now ABB Control has developed a Third Harmonic Filter (THF) which eliminates up to 95% of third harmonics in a network.

In this guidebook, we describe the effects of the third harmonic in networks, the generation and detection of third harmonics and the elimination of third harmonics by means of the THF.

The Third Harmonic Filter - THF

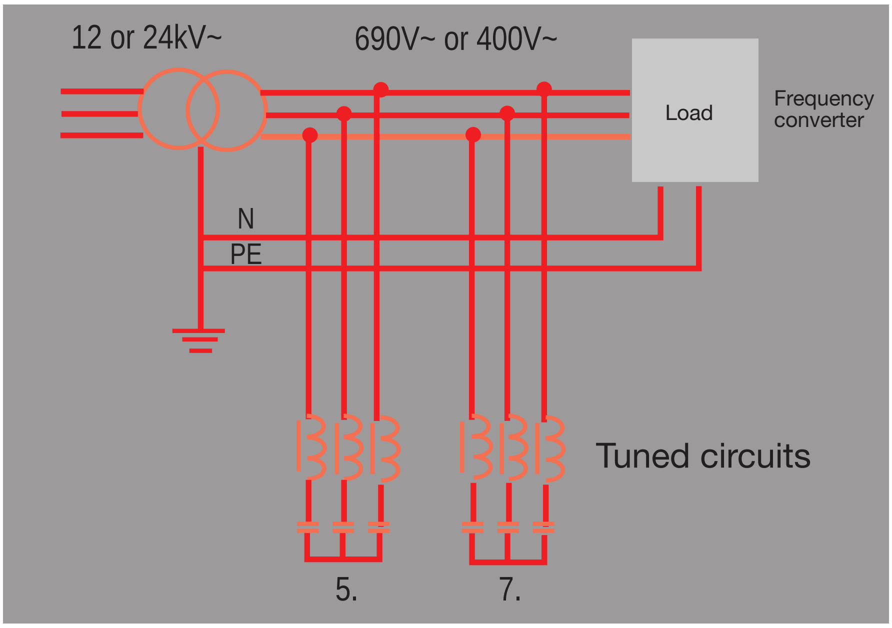
The classification of harmonics

Harmonic	3.	5.	7.	9.	11.	13.	etc.
Frequency/50 Hz	150	250	350	450	550	650	etc.
Sequence	0	-	+	0	-	+	etc.

The effects of harmonics

Sequence	Direction of rotation	Effects
+	forward	Heating
-	backwards	Heating and problems for motors
0	insignificant	Heating of neutral conductor accumulation in neutral conductor

The fifth and seventh harmonics can be filtered out by "tuned circuits". Suck circuits, however, do not eliminate the third harmonic.



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2. Generation of the third harmonic

The increasing use of non-linear equipment, such as discharge lamps and computers, causes problems for networks and other equipment because of their generation of third harmonics. A non-linear load generates a 150 Hz harmonic current in the network. The third harmonic can generate a current in the neutral conductor which is even larger than the current in the phase conductors.

Computers generate considerable levels of third harmonic currents. For instance, a common office-PC generates a 4 A/kW, 150 Hz current in a network.

Equipment that generates third harmonics includes:

- Computers
- Office equipment
- Discharge lamps
- Welding equipment
- Generators
- Rectifiers
- UPS
- Induction furnaces
- Home electronics (TV, radio, microwave ovens etc.)

All discharge lamps, such as fluorescent lamps, mercury vapour lamps, high-pressure sodium lamps, multimetal discharge lamps, halogen lamps, PL-lamps etc. generate harmonics. A discharge lamp will generate a 1 A/kW, 150 Hz current in a network.

The level of harmonics caused by rectifiers is dependent on the number of pulses used by the rectifier. 12-pulse rectifiers generate less harmonics than 6-pulse rectifiers. Three-phase rectifiers do not generate any third harmonic.

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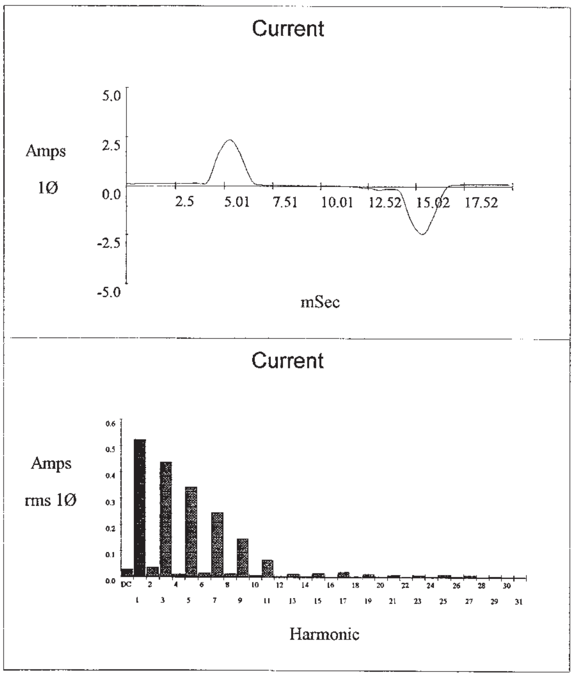
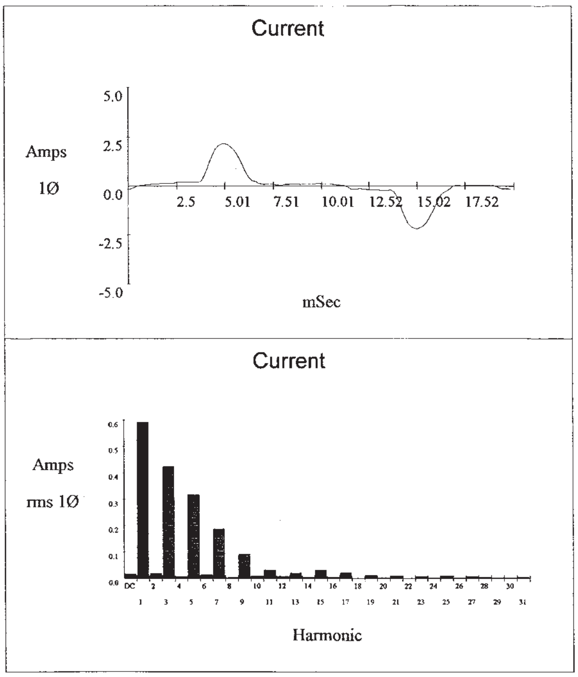




PC-load *TV + video + radio + CD + tape recorder*

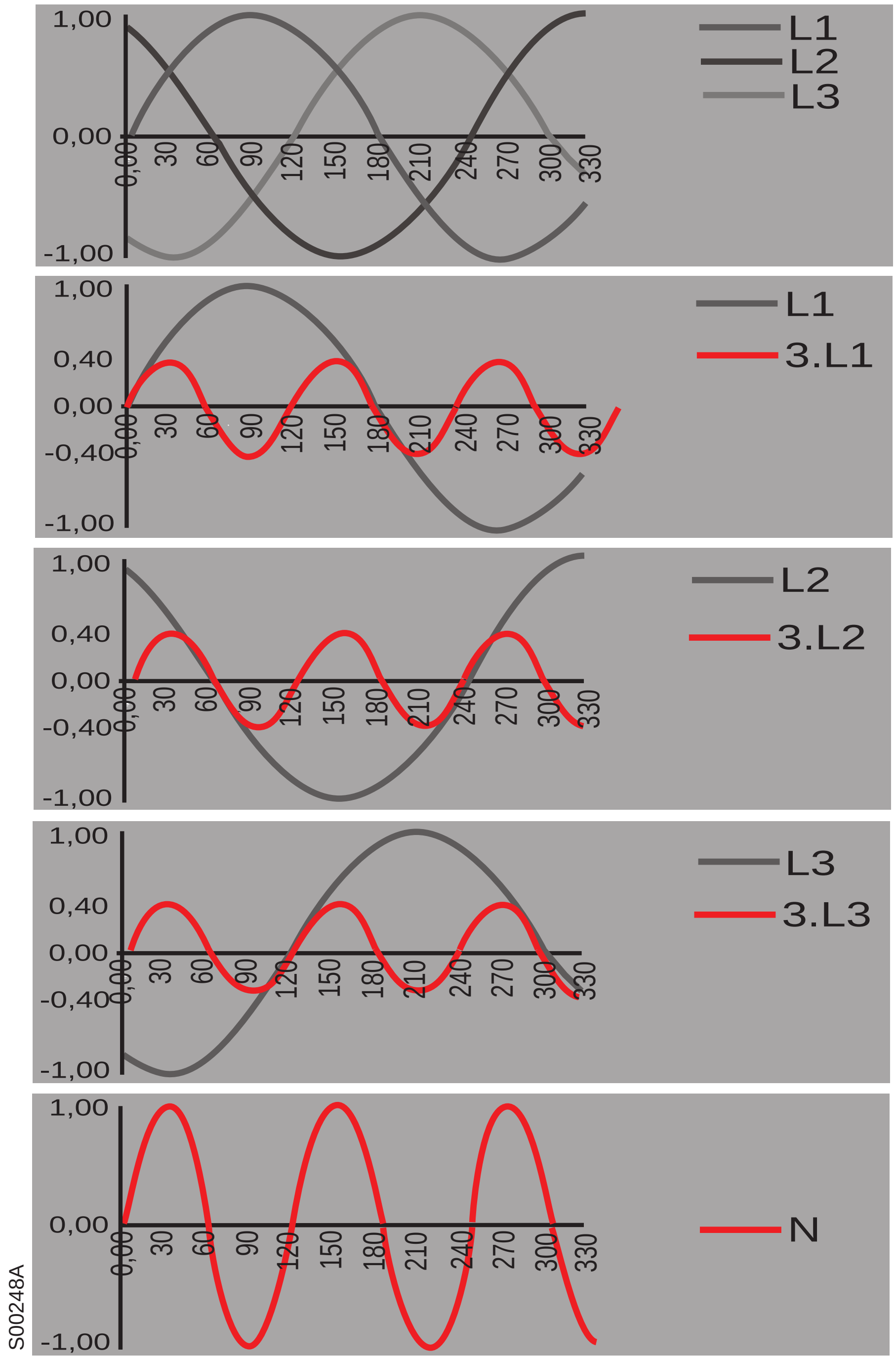
Harmonics and distortion of sine curves caused by different loads:

3. Third harmonics generate large neutral currents

In symmetrical loads, when all three phases are loaded equally, there is no current in the neutral conductor. However, if there are third harmonics in a network, currents also appear in the neutral conductor. The third harmonic is in the same stage in every phase of a three-phase system, causing the current generated by harmonics to accumulate in the neutral conductor.

Within discharge lamp systems, the harmonic content in phase conductors can rise by up to 30 % of the phase current values. Thus, the neutral conductor is loaded with 3 x 30 %, or 0,9 times the phase current. Examples exist of 150 Hz currents being measured in neutral conductors in bank buildings. These were up to three times stronger than the load currents in the phase conductors.

In installations where the dimension of the neutral conductor is only half that of the phase conductor, it is evident that the neutral conductor is overloaded. This can create a fire risk because the neutral conductor is not protected by a fuse.



Third harmonics accumulate in neutral conductors.

The American CBEMA (Computer-Business Equipment Manufacturers Association) has recommended that, due to the risk of fire caused by third harmonics, the cross-section of neutral conductors should be at least 1,73 times the cross-section of the phase conductor. Generally, the cross-section of the neutral conductor is 50 % of the cross-section of the phase conductor.

New regulations have come into force in Sweden and Finland, in accordance with the international EMC-directive. In these regulations, the dimensioning of the neutral conductor must take account of the load in the neutral conductor caused by the third harmonic:

524.2 The cross-section of the neutral conductor must be the same as the cross-section of the phase conductors:
- in single-phase circuits regardless of the cross-section and
- in polyphase circuits, when the cross-section of the phase conductors is up to 16 mm^2 copper or 25 mm^2 aluminium.

524.3 In polyphase circuits, where the cross-section of the phase conductors is larger than 16 mm^2 copper or 25 mm^2 aluminium, the cross-section of the neutral conductor may be smaller than the cross-section of the phase conductors. The following conditions must, however, be simultaneously achieved:

- the strongest current (including harmonics) which may appear in the neutral conductor during normal use, is not bigger than the current capacity of the neutral conductor

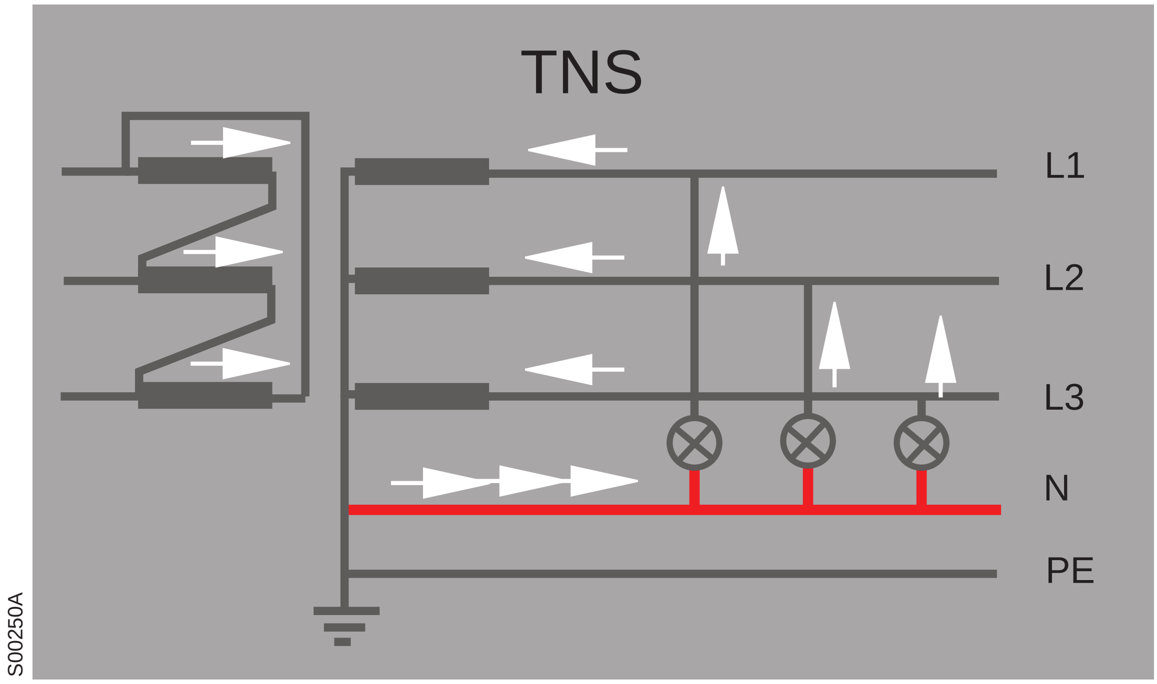
Note: In normal use the load should be divided equally between the phases.

- the neutral conductor is protected against overcurrent according to the regulations

- the cross-section of the neutral conductor is at least 16 mm^2 copper or 25 mm^2 aluminium

Because it is not possible in the planning stage to anticipate the generation of harmonics, the neutral conductors must be overdimensioned or the size of the harmonics must be limited according to the regulations.

Using a THF filter will ensure that generation of third harmonics in the neutral conductor is not possible, eliminating the need to overdimension the neutral conductor.



The third harmonic accumulates in the neutral conductor, overloading it and causing a risk of fire.

3.1 Conductor requirements

The requirements concern cables and insulated conductors that are restricted to 1000 V in alternating voltage circuits and a maximum of 1500 V in direct voltage circuits. The requirements also concern ground cables.

Recommended cables:

Cross-section	A-class U_0/U = 0,6/1 kV				6/10 kV		12/20 kV	B-class 0,6/1 kV
mm²	MCMK	AMCMK	APAKM	AMKA	APAKM	AHXAMK-W	AHKAMK-W	MCMK
3-phase cables								
1,5 2,5	3x2,5 + 2,5							3x1,5 + 1,5
4 6	3x6 + 6							3x4 + 4
10 16	3x10 + 10 3x16 + 16	3x16Al + 10Cu		3x16 + 25				
25 35	3x35 + 16	3 × 35Al + 10Cu		3x35 + 50				3x25 + 16
50 70	3x70 + 35	3x70Al + 21Cu	3x70 + 70	3x70 + 95	3x70		3x70	3x50 + 25
95 120	3x120 + 70	3x120Al + 41Cu	3x120 + 120	3x120 + 95	3x120	3x120	3x120	
150 185	3x185 + 95	3x185Al + 57Cu				3x185	3x185	
240		3x240Al + 72Cu	3x240 + 240					
300						3x300		
1-phase cables								
1,5 2,5	1x1,5 + 1,5 1x2,5 + 2,5							
4 6	1x6 + 6							1x4 + 4

Source: TTT/ABB Oy

The number of loaded conductors in the circuit

In a circuit, the conductors with load current are taken into account. If the load in a polyphase circuit is presumed to be symmetrical, it is not necessary to take the neutral conductor into account. However, there is an exception: if a current appears in the neutral conductor and the load in the phase conductors is not decreased by the same amount, the neutral conductor has to be taken into account when determining the current capacity of the circuit.

Note: In three-phase circuits, this kind of current can be generated by significant harmonics.

Conductors which function only as equipment earth conductors do not need to be taken into account. PEN-conductors have to be taken into account as neutral conductors. (Source: Sähkötarkastuskeskus, publication A2/94)

Table 52 A. The highest operating temperatures for insulation materials

Insulation	Highest permissible temperature °C
Polyvinyl chloride (PVC)	70 (conductor)
Polyethylene (PEX), ethylene proben rubber (ERP)	90 (conductor)
Mineral (PVC covered or open to touch)	70 (sheath)
Mineral (open, untouchable, not in contact with flammable materials)	105 (sheath)

Note:

1) The temperatures in the table are in accordance with the standards IEC 502 and IEC 702.

2) Higher ambient temperatures for mineral insulated cables are possible depending on how well the cables resist temperature. Also, the connections and environmental conditions and other extrinsic factors have effects on highest permissible temperatures.

Table 52-X3

Correcting factors for groups of more than one circuit or for more than one polyconductor cable.

(To be used with the current capacity values in tables 52-X1 and 52-X2. Not for installation type D)

Point	Installation type	The number of circuits or polyconductor cables								
		1	2	3	4	6	9	12	15	20
1	built-in or closed	1,00	0,80	0,70	0,70	0,55	0,50	0,45	0,40	0,40
2	One layer on wall, floor or on non-perforated cable tray	1,00	0,85	0,80	0,75	0,70	0,70	-	-	-
3	One layer on ceiling	0,95	0,90	0,70	0,70	0,65	0,60	-	-	-
4	One layer on perforated horizontal or vertical tray	1,00	0,90	0,80	0,75	0,75	0,70	-	-	-
5	One tier on cable rack, brackets etc.	1,00	0,85	0,80	0,80	0,80	0,80	-	-	-

Source: Sähkötarkastuskeskus, publication A2/94

Table 52-X1. PVC-insulation

The current capacity of PVC-insulated cables with different installation methods

A/mm²	A		B		C		D		E		F			G	
	2 conductors	3 conductors	2 conductors	3 conductors	2 conductors	3 conductors	2 conductors	3 conductors	2 conductors	3 conductors	2 conductors	3 conductors in a triangle	3 conductors flat cable	3 conductors flat cable, horizontal	3 conductors flat cable, vertical
Copper															
1,5	15	13,5	18,5	16	20	18,5	33	26	23	19,5	-	-	-	-	-
2,5	20	19	25	22	27	25	43	36	31	26	-	-	-	-	-
4	27	25	33	29	37	33	56	46	42	36	-	-	-	-	-
6	36	32	43	38	48	43	71	57	54	45	-	-	-	-	-
10	48	44	60	53	66	60	91	78	74	63	-	-	-	-	-
16	64	59	80	72	90	80	123	101	99	84	-	-	-	-	-
25	84	77	107	94	118	101	157	130	126	107	138	116	120	154	137
35	104	94	132	117	146	126	189	156	156	133	171	145	151	191	171
50	126	114	160	142	178	152	224	185	191	162	207	177	184	232	208
70	160	144	203	181	225	195	278	228	245	207	266	228	238	297	269
95	192	173	245	219	273	236	327	271	298	252	322	279	291	361	329
120	222	199	285	253	316	274	373	308	347	292	373	325	339	419	383
150	254	228	-	-	364	311	421	349	401	338	430	377	393	483	444
185	289	262	-	-	415	361	473	389	460	385	490	431	451	552	508
240	339	303	-	-	488	427	547	450	543	455	578	510	534	651	603
300	389	347	-	-	561	491	618	510	629	526	666	589	616	751	698
400	-	-	-	-	-	-	-	-	-	-	799	703	739	903	842
500	-	-	-	-	-	-	-	-	-	-	920	802	844	1040	975
630	-	-	-	-	-	-	-	-	-	-	1065	907	952	1206	1134
Aluminium															
16	50	45	62	56	69	62	94	78	77	64	-	-	-	-	-
25	66	60	83	73	87	77	121	100	94	82	103	89	92	118	104
35	81	74	103	91	109	96	144	121	117	101	129	111	115	147	131
50	98	89	125	111	132	116	171	142	143	124	157	135	140	179	161
70	125	113	159	140	169	148	213	176	183	159	203	175	183	230	207
95	150	136	191	170	206	180	252	208	222	192	249	215	224	280	255
120	173	157	222	197	239	208	286	237	258	224	289	251	261	326	298
150	200	180	-	-	276	240	323	269	298	259	334	290	304	377	345
185	227	205	-	-	315	274	365	304	341	296	384	333	349	431	398
240	267	240	-	-	373	323	420	349	402	349	455	397	415	510	473
300	306	276	-	-	430	372	475	395	465	403	526	460	482	590	550
400	-	-	-	-	-	-	-	-	-	-	636	557	585	711	666
500	-	-	-	-	-	-	-	-	-	-	735	646	678	821	773
630	-	-	-	-	-	-	-	-	-	-	856	752	790	954	903

Table 52-X2. PEX/EPR-insulation

The current capacity of PEX/EPR-insulated cables with different installation

A/mm²	A		B		C		D		E		F			G	
	2 conductors	3 conductors	2 conductors	3 conductors	2 conductors	3 conductors	2 conductors	3 conductors	2 conductors	3 conductors	2 conductors	3 conductors in a triangle	3 conductors flat cable	3 conductors flat cable, horizontal	3 conductors flat cable, vertical
Copper															
1,5	19,5	17,5	23	20	24	22	39	31	27	23	-	-	-	-	-
2,5	27	23	32	28	34	31	50	43	37	33	-	-	-	-	-
4	36	32	43	38	46	41	65	55	50	43	-	-	-	-	-
6	46	41	56	49	60	54	84	68	65	56	-	-	-	-	-
10	63	56	76	68	83	73	108	91	89	78	-	-	-	-	-
16	84	75	104	92	111	99	142	118	119	104	-	-	-	-	-
25	110	98	138	121	143	123	181	152	154	132	167	140	146	189	167
35	136	121	170	149	177	152	218	182	192	163	208	175	183	235	209
50	164	146	205	182	218	186	259	215	234	199	251	215	223	286	255
70	208	186	264	230	279	238	320	268	300	255	322	278	290	367	330
95	250	224	318	279	341	289	379	317	366	309	392	341	354	447	404
120	289	258	368	324	397	334	431	360	426	359	454	397	414	520	472
150	330	296	-	-	458	385	486	407	491	414	524	460	480	600	548
185	376	336	-	-	526	440	546	457	563	474	598	526	552	687	629
240	440	395	-	-	622	520	630	528	666	559	706	628	656	812	747
300	505	452	-	-	720	599	713	573	770	644	814	726	760	938	866
400	-	-	-	-	-	-	-	-	-	-	977	872	915	1128	1048
500	-	-	-	-	-	-	-	-	-	-	1125	996	1046	1303	1215
630	-	-	-	-	-	-	-	-	-	-	1304	1120	1161	1512	1416
Aluminium															
16	66	60	82	73	87	79	108	91	94	80	-	-	-	-	-
25	87	79	109	96	105	93	139	117	112	100	125	107	111	143	126
35	104	97	136	120	131	116	168	140	140	124	156	134	140	178	159
50	130	117	164	145	160	141	198	168	171	152	191	165	171	218	195
70	164	147	208	186	205	180	244	207	219	194	246	217	223	281	253
95	198	177	251	224	250	219	289	246	267	236	300	263	274	345	312
120	228	204	292	260	291	254	330	279	312	273	350	307	320	402	365
150	263	235	-	-	336	294	373	315	359	314	404	356	372	465	424
185	299	266	-	-	385	335	420	355	412	359	464	410	429	535	488
240	351	312	-	-	456	395	482	408	488	425	551	489	511	635	583
300	402	358	-	-	527	457	547	463	564	489	637	568	593	736	678
400	-	-	-	-	-	-	-	-	-	-	769	689	721	890	823
500	-	-	-	-	-	-	-	-	-	-	890	800	838	1030	957
630	-	-	-	-	-	-	-	-	-	-	1035	934	979	1225	112

Source: Sähkötarkastuskeskus, publication A2/94

Notes for installation methods

Installation methods A and A2

1. Insulated conductors or polyconductor cables in a cable conduit situated inside an insulated wall:
The structure of the wall is as follows: Waterproof exterior surface, thermal blanket and wooden or equivalent interior surface with thermal conductivity of 10 W/m2 K. Cable conduit is fixed near the interior surface, but not necessarily touching it. It is presumed that the heat transmission from the cables takes place only via the wall's interior surface. The cable conduit can be made of metal or plastic.

Installation methods B and B2

2. Insulated conductors or polyconductor cables in a cable conduit situated on wooden wall:
The cable conduit is fixed on a wooden wall, so that the distance between the wall surface and the cable is less than 0,3 times the diameter of the conduit. The cable conduit can be made of metal or plastic.

Installation method C

3. A cable on a wall surface:
The cable is fixed on a wooden wall, so that the distance between the wall surface and the cable is less than 0,3 times the diameter of the cable. If a cable is fixed on or inside a wall made of a brick like material, the current capacity of the cable can be higher.

4. A cable on a floor or ceiling:
As for number 3. The current capacity of a cable which is fixed on a ceiling is somewhat less than that of a cable on a floor or on a wall (see table 52-E1).

Installation method D

5. A cable installed in the ground:
The cable is in immediate contact with the surrounding soil. The current capacity values in the tables are based on the thermal resistance of the ground (1.0 K m/W) and the depth of the installation (0,7 m.)

6. Cables in duct-works:
A cable which is installed in a duct, which is placed directly into soil and not made of metal. The current capacity values in the tables are based on the thermal resistance of the ground at a depth of 0,7 m. These values can also be used for polyconductor cables if they are installed in a metal pipe.

Installation methods E, F and G

7. A cable suspended in the air:
A cable is hung so that the total coefficient of thermal conductivity is easy to determine. The warming-up effect of the sun and other sources must be taken into account. Care must be taken to ensure that the natural circulation of air is not restricted. In practice, it is possible to use the current capacity values of cable which is installed freely in the air if the distance between the cable and a nearby surface is at least 0,3 times the diameter of the cable.

Installation methods H, J, K, M, N and P

8. On a perforated cable tray, there are holes at regular distance for fixing the cable: If the area of the holes is less than 30% of the area of the tray, it is considered that the tray is not perforated.

Installation methods L and Q

9. Cable rack:
This construction impedes the air circulation around cables as little as possible. The area of supporting metal parts is less than 10 % of the total.

10. Clamps, brackets:
Clamps which fix the cable at regular distances and allow almost completely free circulation of air around the cable. (Source: Sähkötarkastuskeskus, publication A2/94)

3.2 Problems caused by the third harmonic

The strong neutral currents generated by the third harmonic cause, among other things, the following problems:

In a network:
- Overheating of the neutral conductor leading to the risk of fire
- Increased power losses
- Strong electromagnetic fields
- Causes the network to produce interference

Harmonics cause interference in electrical plant:

In transformers:
- Increased power losses
- The risk of resonance
- Overload of delta windings due to rotating third harmonic current
- Decreased operating life
- Noise
- Temperature rises

In capacitors:
Capacitors are especially sensitive to harmonics. Batteries must be overdimensioned in order to withstand them.
- Increased power losses
- The risk of resonance
- Decreased operating life

In cables and conductors:

- Increased power losses
- Overload on neutral conductor (N- and PEN-conductors) The third harmonic accumulates in the neutral conductor, making the 150 Hz harmonic three times stronger than in the phase conductors.
- The risk of fire. The neutral conductor can burn out.

In computers:

- The risk of malfunction. Harmonics may cause mysterious interference effects.

Other interference:

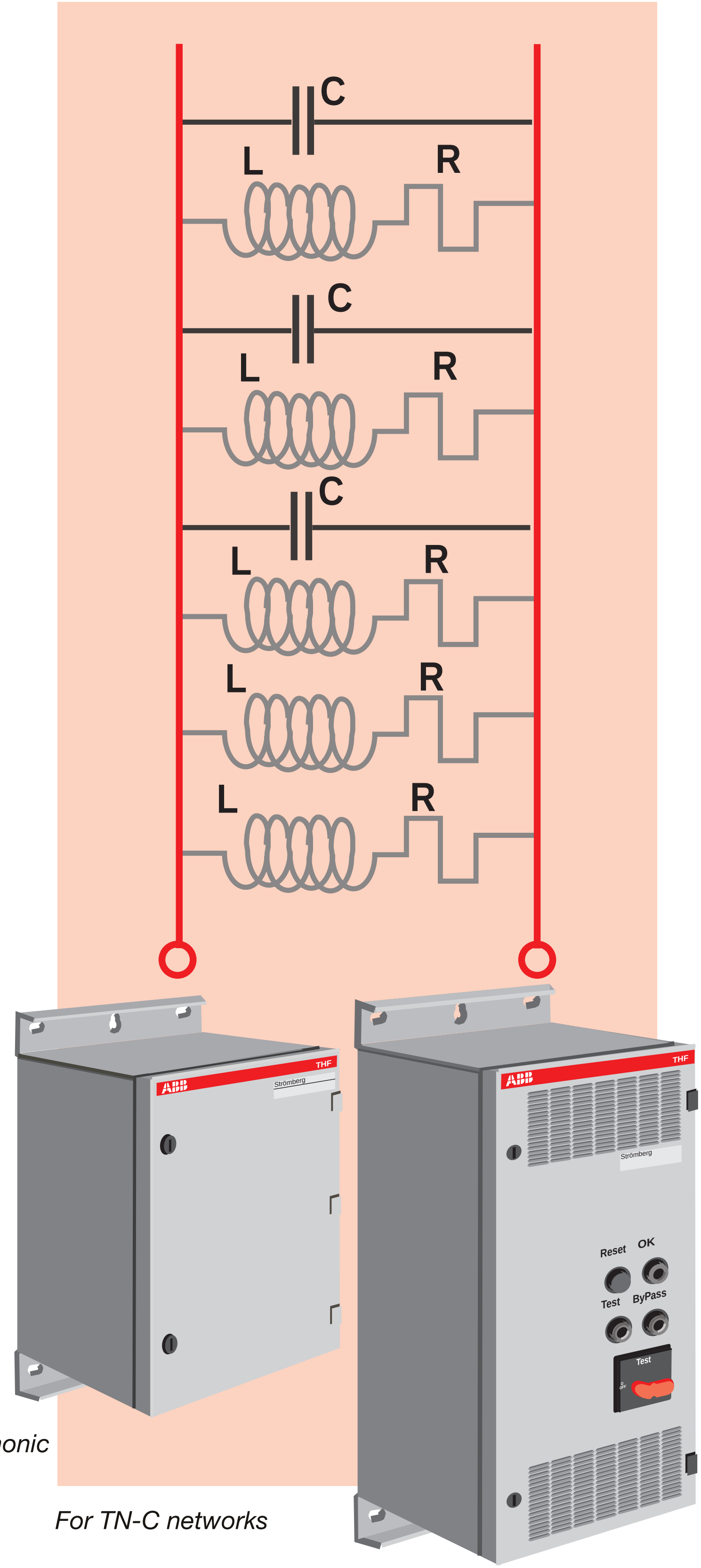
- Malfunctions of electrical equipment
- Malfunctions of electronic relays
- Malfunctions of earth fault alarms
- Unrequested operation of appliances
- Malfunctions of control devices
- Strong electromagnetic fields
- Potential differences in 4-conductor systems. This could be caused by the 150 Hz fault current caused by the third harmonic in PEN-conductors. Potential differences may cause malfunctions in computers.

4. Third Harmonic Filters (THFs)

Third Harmonic Filters eliminate the problems caused by the third harmonic. They also considerably decrease the electromagnetic fields and power consumption. The decrease in the power consumption can give savings between 4 and 9 % in energy consumption. There will also be other savings, due to the decrease of maintenance costs for equipment.

The THF manufactured by ABB Control Oy eliminates about 95 % of the 150 Hz current in a neutral conductor if the dimensioning is correct. It does this by forming a high resistance at 150 Hz. This is obtained by trimming an inductance and a capacitance, coupled in parallel, to resonate at the third harmonic frequency. The THF also eliminates the 150 Hz current in the phase conductors and decreases the energy consumption and voltage resonance. It therefore increases, among other things, the operating life of capacitors and considerably decreases maintenance costs. A patent has been applied for this method.

- **The THF eliminates about 95 % of the third harmonic current (150 Hz) in the neutral conductor**



The Third Harmonic Filter (THF)

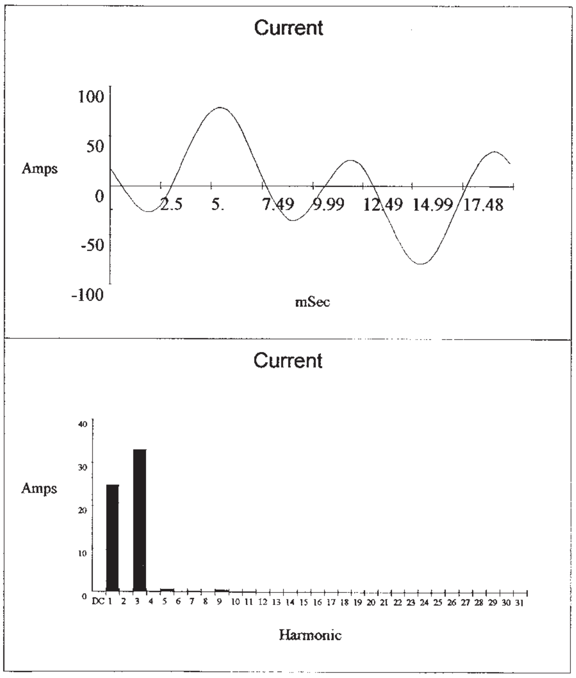
For TN-C networks

For TN-S networks

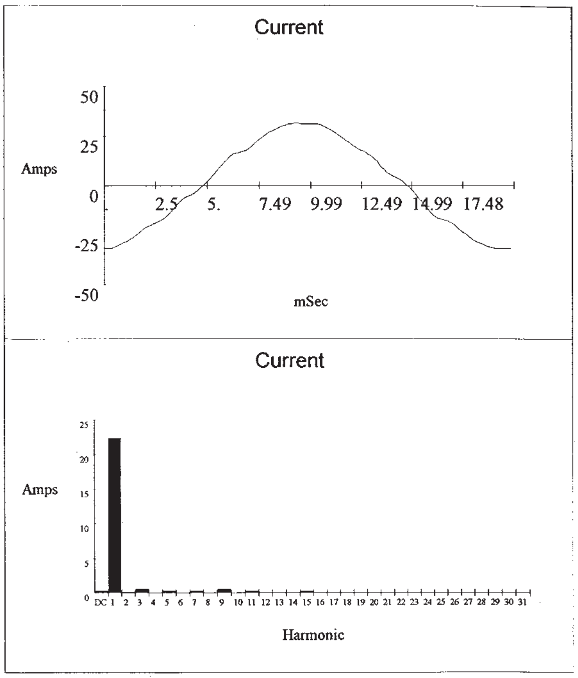
4.1 Eliminating third harmonic problems

The elimination of the third harmonic from the neutral conductor also eliminates problems in the network and operating problems in equipment.

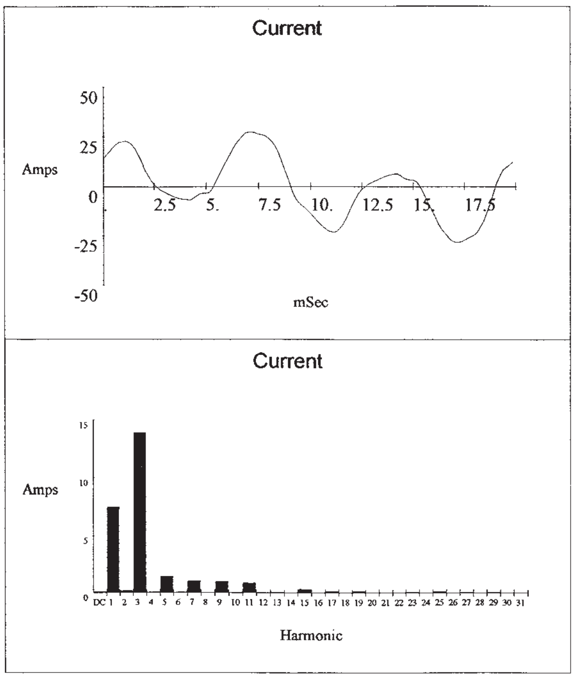
- The THF eliminates about 95 % of the third harmonic current (150 Hz) in the neutral conductor
- The risk of fire decreases when this load, which strains the neutral conductor, disappears. Overdimensioning of the neutral conductor can therefore be avoided.
- The operating temperature of transformers decreases, increasing their lifetime.
- A THF also eliminates 150 Hz current from the phase conductors, decreasing the power consumption by 4-10 %. This gives considerable savings in energy consumption.
- Decreases magnetic fields by 80 %.
- The quality of the network improves when the interference caused by the third harmonic disappears.



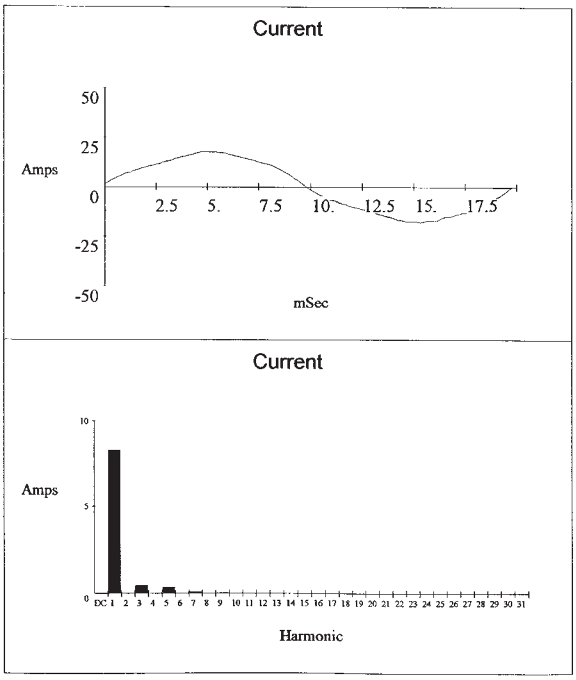
Installation in a green house. 100 x 400 W high-pressure sodium lamps, 3-phase network ***without filter****, N-conductor current.*



Installation in a green house. 100 x 400 W high-pressure sodium lamps, 3-phase network THF 63 ***filter installed****, N-conductor current.*



Huddinge hospital. ***Without filter****, N-conductor current.*



Huddinge hospital. THF 125 ***filter installed****, N-conductor current.*

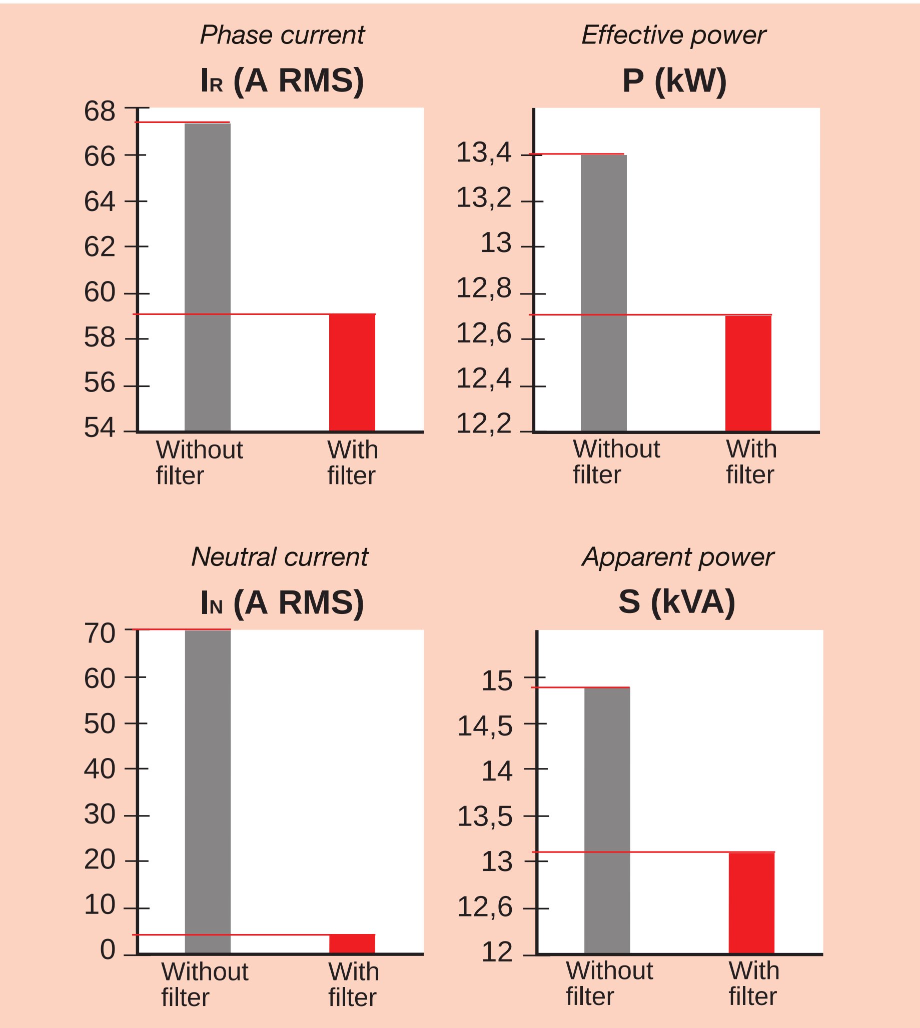
4.2 Decreasing the risk of fire

The current in a neutral conductor can in some cases exceed the value of the phase current. For example, a 70 mm^2 phase conductor has been dimensioned so that the temperature does not exceed the temperature rating of the insulation. Since the cross-section of the neutral conductor is generally only about a half the cross-section of the phase conductor, the harmonic current, which accumulates in the neutral conductor, may cause over heating, earth fault and short circuit. In the worst case, the conductor may break off, because the short circuit protection does not protect the neutral conductor against overload.
Since a THF eliminates the third harmonic from the neutral conductor, it also eliminates these problems, as well as the risk of fire.

4.3 Energy savings

The THF also saves energy. When the third harmonic is almost totally eliminated from the neutral conductor, the 150 Hz current component is also eliminated from the phase conductors. In practice, this gives energy savings or the possibility of increasing lighting capacity without increasing energy consumption.

The following test results were achieved at a Scania factory in Sweden: The neutral current decreased by 95 % and power consumption by 6 %. The load on transformers decreased and the magnetic field in the premises also decreased considerably. Scania calculated that it will save about 1 million Swedish crowns per year by installing THFs in all its business premises.
Shown below is an example of a measurement at the test plant:



A test result at the test plant. Lighting group 125 A fuse

ABB

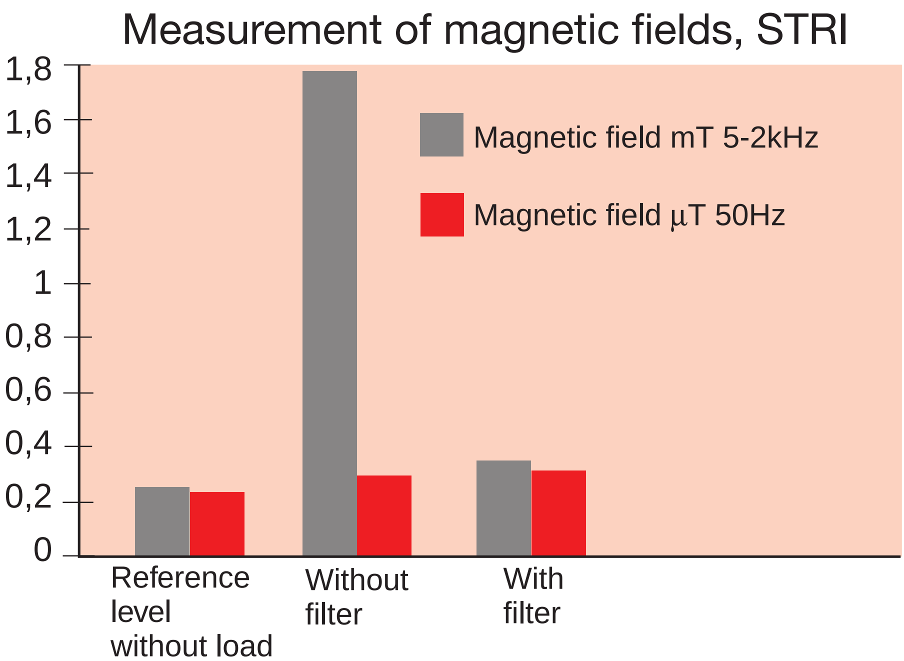
4.4 Decreasing the magnetic fields

Recently, there has been debate about the possible health risks of magnetic fields generated by electrical equipment. The EU is to publish the limit values for magnetic fields in public and working places. Reducing magnetic fields by altering or replacing existing equipment is in many cases impossible.
However, the problem can be solved by THFs. In a Swedish office, where a THF was installed in a distribution centre, measurements showed that the magnetic field had decreased by 70 %. In Huddinge hospital in Sweden, magnetic fields have decreased considerably after the installation of a THF. A consequence of the decrease of magnetic fields was the improvement of the reliability of alarm devices.

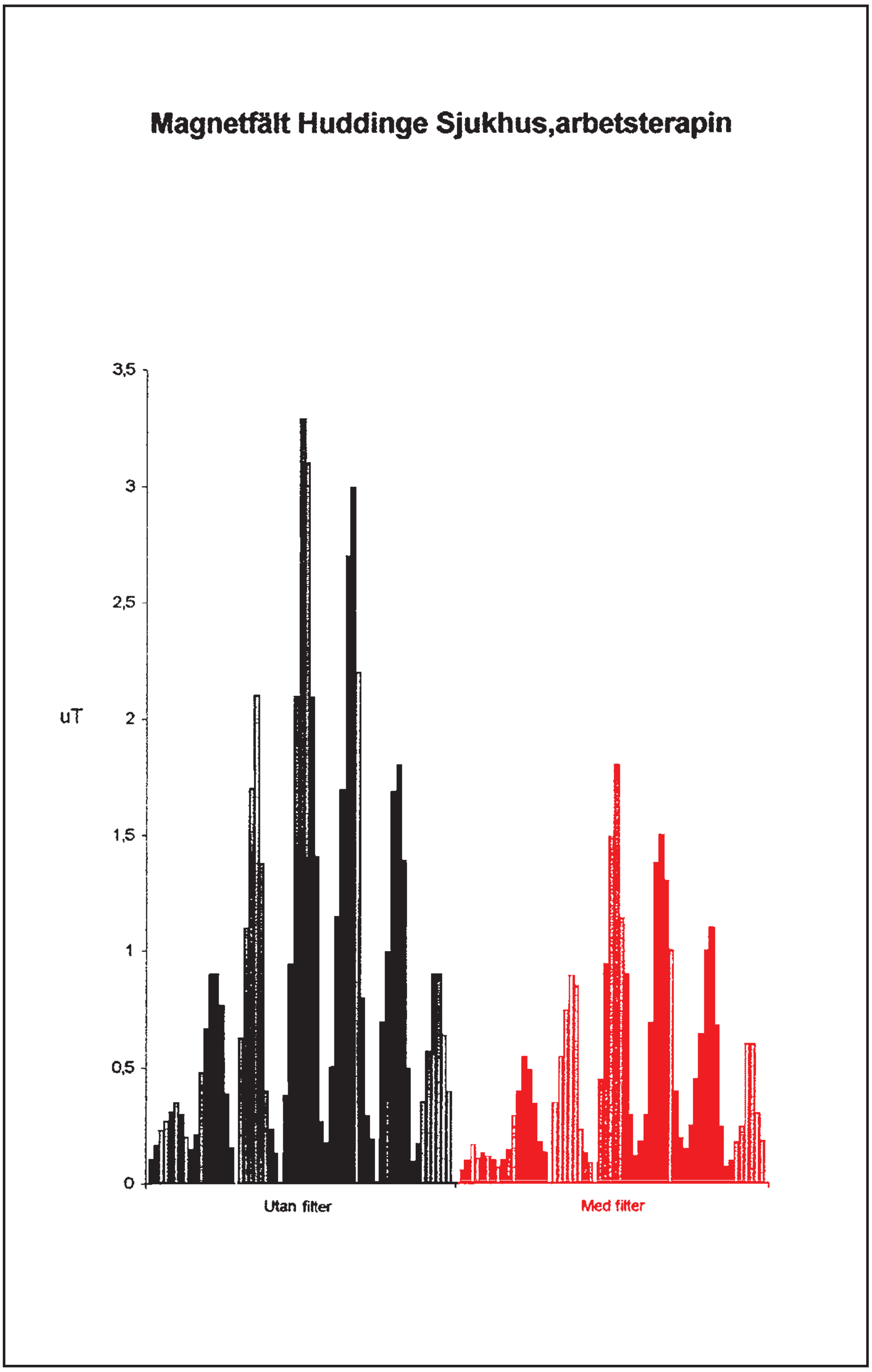
In Sweden, 0,2 microTesla has been set as the upper limit for continuous exposure to low frequency magnetic fields in public places.

The metering was carried out in a 20 m2 room, with the sensor at a height 0,5 m.

STRI= Swedish Transmission Research Institute



The measuring of magnetic fields in Huddinge hospital,
left: columns without filter, right: with filter.
Measurements were taken at different points in the room.

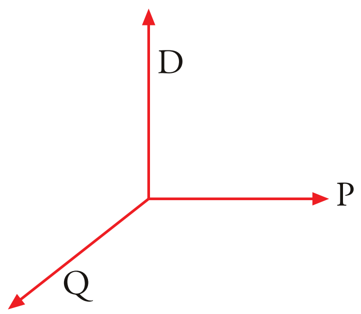


5. Voltage distortion

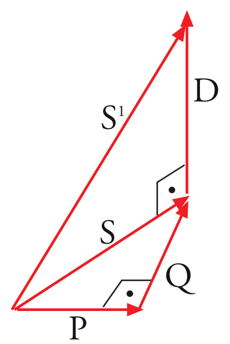
All non-linear loads need a 150Hz voltage generated by the current of the third harmonic.

A THF generates this 150 Hz voltage, and so the non-linear load does not need to take 150 Hz current from the network. The THF generates a counter voltage against the 150 Hz voltage generated by the load and therefore decreases the voltage distortion.

The voltage itself does not generally cause problems, but the current caused by the voltage does. A particular problem is, for instance, rising temperature. The THF generates a counter voltage and as a consequence the current vanishes. This is why the main objective of the THF is to eliminate the current, not the voltage.



P = Active Power
Q = Reactive Power
D = Distortion



S = Apparent Power
S' = Apparent Power with a load generating harmonics

6. Installation of the filter in different networks

6.1 The most common network structures and methods of grounding

According to the IEC publication 364-3 (1977) part 3, distribution systems are marked with a letter code, which has the following meanings:

First letter: Grounding type of the distribution system
T = one point is connected directly to earth (T=terrain)
Second letter: The grounding of the parts of equipment which can be touched and may become live
N= The touchable parts which may be exposed to voltage are connected to the grounded point of the distribution system (in an a.c. network, generally to the grounded star-point) (N = neutral)
Possible additional letters: The respective arrangement of neutral and equipment earth conductors
S = separate neutral and equipment earth conductors (S=separated)
C= neutral and equipment earth conductors are combined into one (PEN) conductor (C=common).

In this system, one point is connected directly to earth, and the touchable parts which may be exposed to voltage are connected to this point by equipment earth or PEN conductor.

On next page are shown the most common network types in which THFs can be installed.

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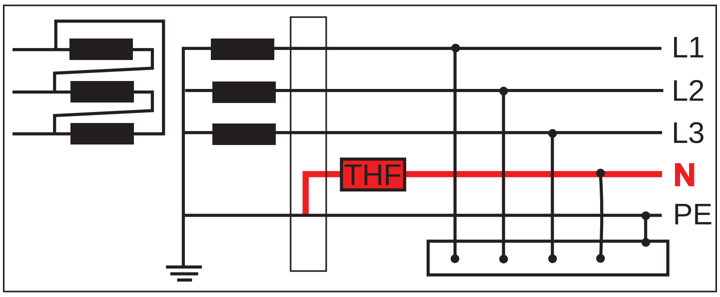
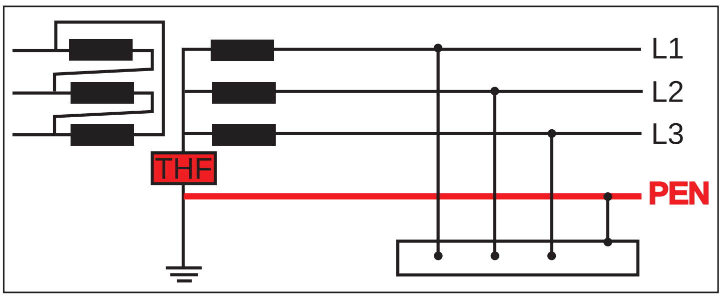
TN-S system

Separate neutral and equipment earth conductors for the whole system. (equipment earth system, 5-conductor system)
The THF is installed in the neutral conductor. The network must be a pure TN-S system. Fault current monitoring is recommended (see 6.3).

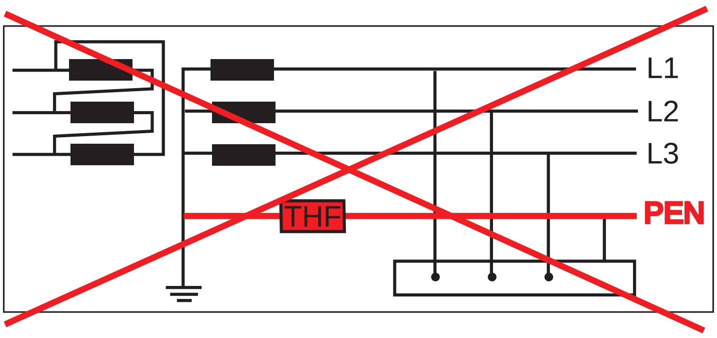


TN-C system (four-conductor system)

These systems utilise a PEN conductor, which acts as both equipment earth (PE) and neutral (N) conductors. The low-voltage distribution systems of electrical utilities generally operate on a TN-C system. The THF is installed at the star point of a transformer.



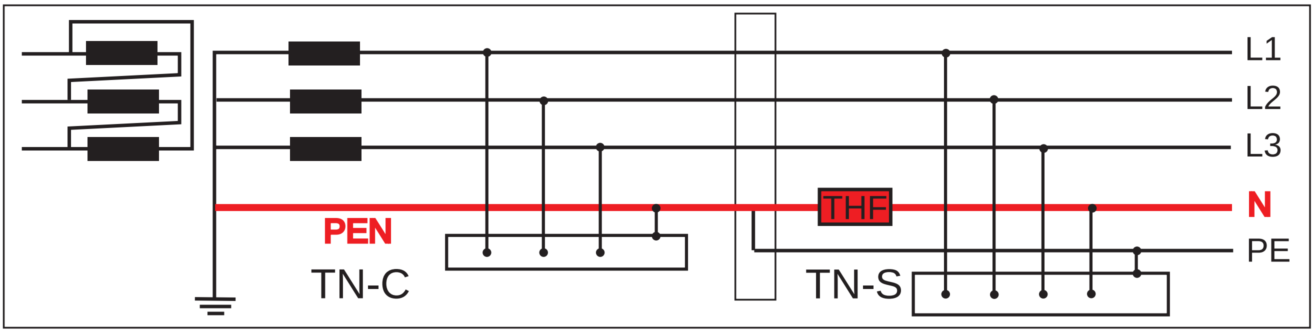
Because of terrestrial currents, THF filters cannot be installed in the PEN conductor of a four-conductor system.



ABB

TN-C-S system

The TN-C-S system is used in ordinary buildings in Finland. The use of TN-S systems has been obligatory only in medical premises, premises where there is a danger of explosion and in cattle houses according to the electrical safety regulations (A1-80). The use of TN-S systems has been extended in regulations (A1-89 and T 86-91) so that they now have to be used in the low voltage distribution systems of junctions (TN systems). Thanks to the system's interference protection and simplicity, it has been recommended that TN-S systems be used for all electrical installation of junctions.



The neutral and equipment earth functions are combined in a part of a TN-C-S system. The THF would be installed at the star point or in the neutral conductor of the TN-S. In a TN-S system, the network must be a pure TN-S system. Fault current monitoring is recommended (see 6.3).

NOTE: The network cannot be grounded after the filter. A consequence of this could be a terrestrial current that passes the filter and goes between the star point of the transformer and the consumer point, for example along iron fittings.

6.2 Generation of interference in the network

When an electronic system consists of various devices, there are often interferences within the earthing of the network. Experience has shown that most of this interference appears in TN-C-S (TN-C) systems (four-conductor systems), where a PEN conductor is used entirely or partly for equipment earth.

There are two ways for interference to build up in TN-S-S or TN-C systems:

The voltage drop caused by the load current in the PEN-conductor connects itself directly between the frame parts of devices with equipment earth. These devices are connected to different points of the network; in this way, interference gets further into the signal conductors, which are linking the devices.

In addition to the earthing at the star point of a transformer, a PEN-conductor is connected to earth at various points of the network because of, for example, potential equalising. In addition, a PEN-conductor will be unintentionally earthed through the frame parts of devices that are in connection with it. In this way, a part of the load current in the PEN-conductor can go through pipelines, frame structures etc., forming circuits which induce interference in signal circuits. The induction effect is particularly strong on circuits which are formed by signal conductors and earth.

In the interference mentioned above, there is often, in addition to a 50 Hz component, a strong 150 Hz component. This is due to odd harmonics, which are divisible by three, occurring in the same phase in all parts of the system and therefore the current caused by them accumulates in the neutral conductor.

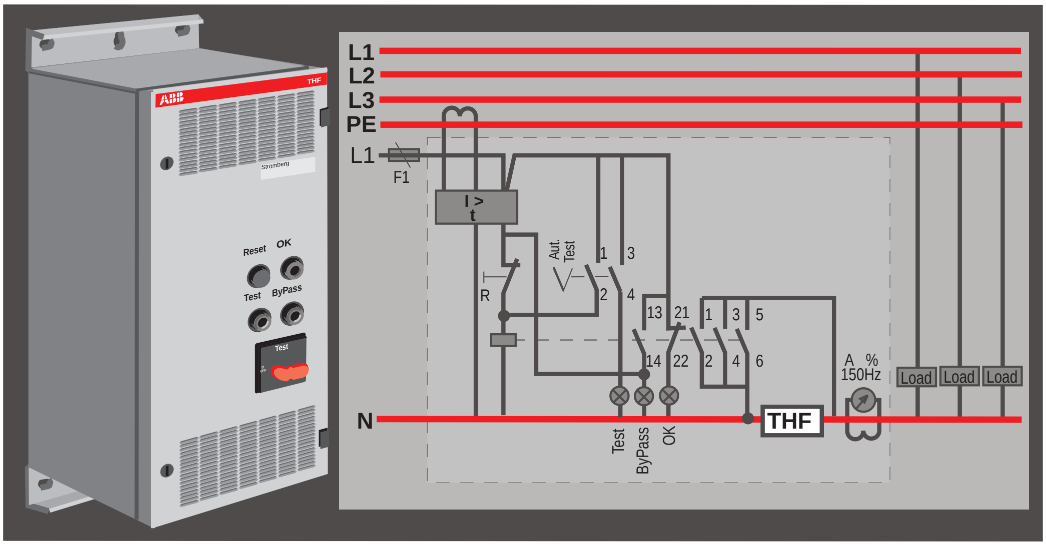
The use of TN-S systems from the point of repulsing the interference

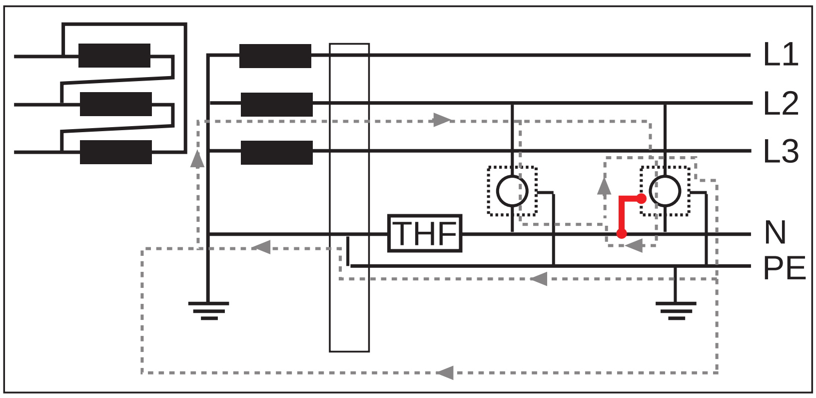
In an ideal case in a TN-S system, the neutral current can not propagate through metal structures, pipelines etc. However, the third harmonic also stresses the neutral conductor.

6.3 Fault current monitoring in the TN-S system

It is advisable to use fault current monitoring in TN-S systems. Fault current monitoring is an alarm system, which monitors the neutral and equipment earth conductors and the insulation status between the phase conductors and earth.

A THF filter can be equipped with a fault current monitoring system, an economic way of improving the protection level of the network. The earth leakage control of THF does not substitude the earth leakage protection required in special applications.





The earthing in this diagram is incorrect; the connection is shown in red. If the THF filter is coupled to the N-conductor, the 150 Hz current can go through the PE-circuit (the grey dotted line).

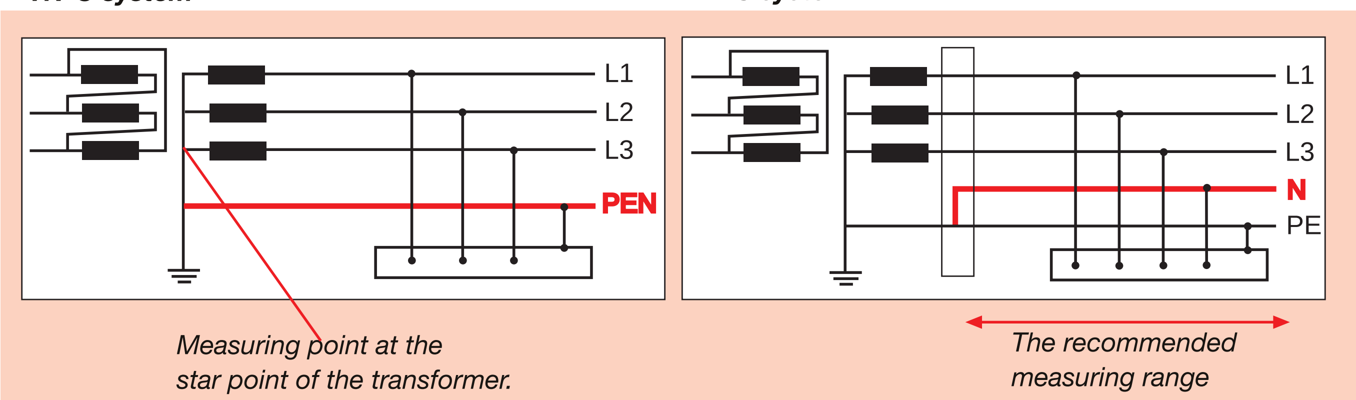
7. Determination of the harmonic

Before measuring harmonics, we must be sure which network system is in question. Measurements must take place at a point of the network where possible harmonic terrestrial currents cannot pass the meter. The measuring ranges for different network systems are shown in the following drawings.

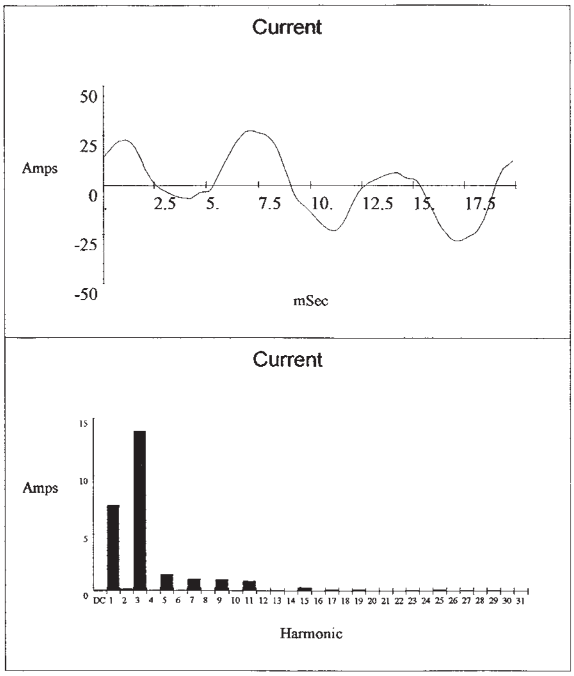
If there are several earthing points in the network, the network has to be "cleaned" in order to obtain reliable results. In TN-S systems, the sum of the 150 Hz current measured in phase conductors must be equal to the 150 Hz measured in the neutral conductor: $I_{LI\ (150\ Hz)} + I_{L2(150\ Hz)} + I_{L2(150\ Hz)} = I_{N\ (150\ Hz)}$. If this condition does not arise, it means that the N- and PE-conductors are in touch with each other and the network has to be cleaned before the installation of a THF. See the terrestrial current drawing on the previous page.

Measurements are best made with a multichannel instrument suitable for this purpose, with a fork ampere meter (True-RMS-meter) or with an oscilloscope. The measurements must only be done by a suitably qualified person and must be made in accordance with the local electrical safety regulations. The possible effect of the measurement on the network must also be taken into account.

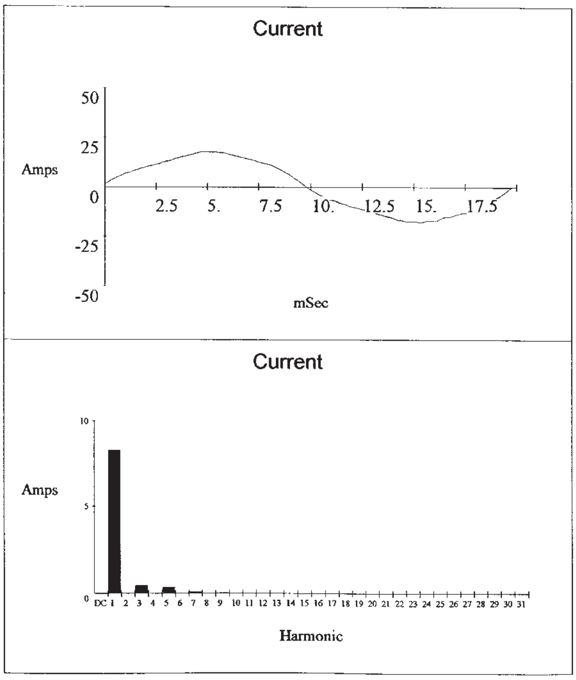
TN-C system ***TN-S system***



7.1 A typical measurement result before and after the installation of the filter

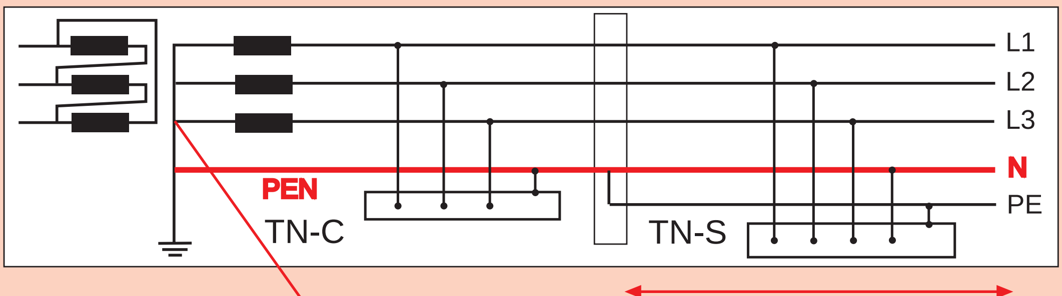


*Huddinge hospital. **Without filter**, N-conductor current.*



*Huddinge hospital. THF 125 **filter**, N-conductor current.*

TN-C-S system



Measuring point at the star point of the transformer.

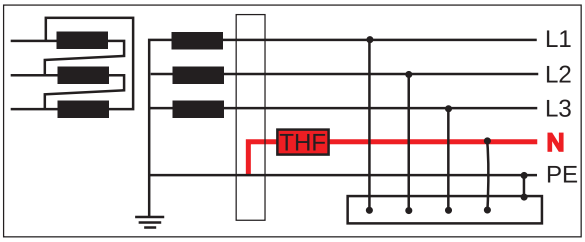
The recommended measuring range

8. Choosing and installing THFs

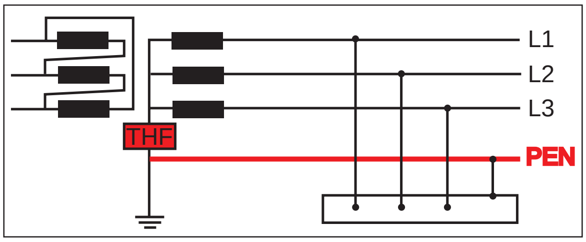
The basis of the factory dimensioning of the filter is the fact that a filter installed in the neutral conductor bears, in addition to the 150 Hz current, a 50 Hz component the size of the phase current (unsymmetrical load).
In the dimensioning of large (over 630 kVA) filters, the simultaneity factors of the network have been taken into consideration.

A filter is sized according to the distribution board or to the fuse, which is supplying the group. In a 5-conductor system, the filter will be in the neutral conductor. In this case, there is a slight voltage in the neutral conductor, but it has no harmful effects. In this case, you must ensure that the network is a pure TN-S system. We recommend fault current monitoring in this case (see 6.3).

TN-S system

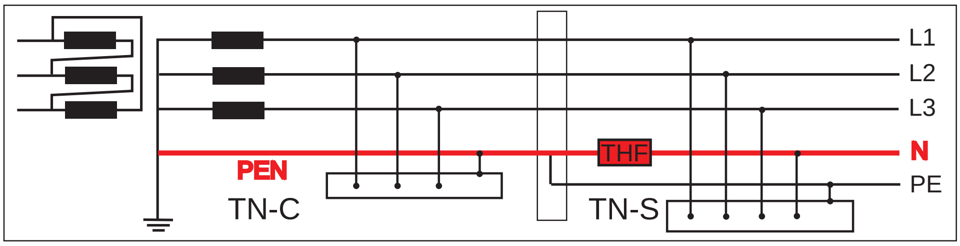


TN-C system



In 4-conductor systems and in mixed networks the filter will be installed at the star point of the transformer. In the TN-S system, part of a mixed network, the filter can also be installed in the neutral conductor. In this case, there is a slight voltage in the neutral conductor, but it has no harmful effects. In this case, you must ensure that the network is a pure TN-S system. We recommend fault current monitoring in this case (see 6.3).

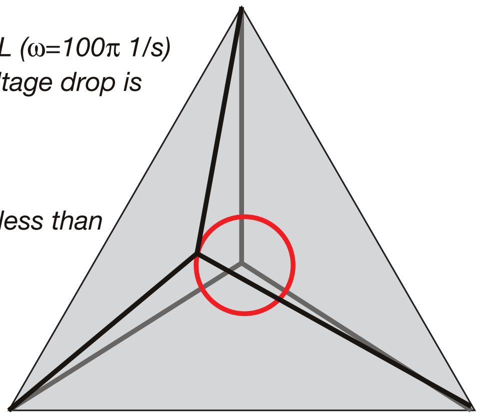
TN-C-S system



Currently, three basic sizes of THF filter are manufactured. They are dimensioned for 63A, 125A and 160A currents. Filtering for larger currents is obtained by parallel connection of filters.

*The 50 Hz impedance of the filter Z(50)=X(50)=9/8*ω*L (ω=100π 1/s)*
*When a full phase current goes through the filter, a voltage drop is generated in the filter dU=In*sin α*X(50)*
When cos α = 0,8, sin α = 0,6 (the angle of phase difference, α = 37 degrees)
The start point for dimensioning the filter is that dU is less than 5 % of the phase voltage (Diagram).

For example: Un=400 V ja sin α=0,6
L<54 mH/(In/A)
THF 63 (In=63 A); L=0,85 mH



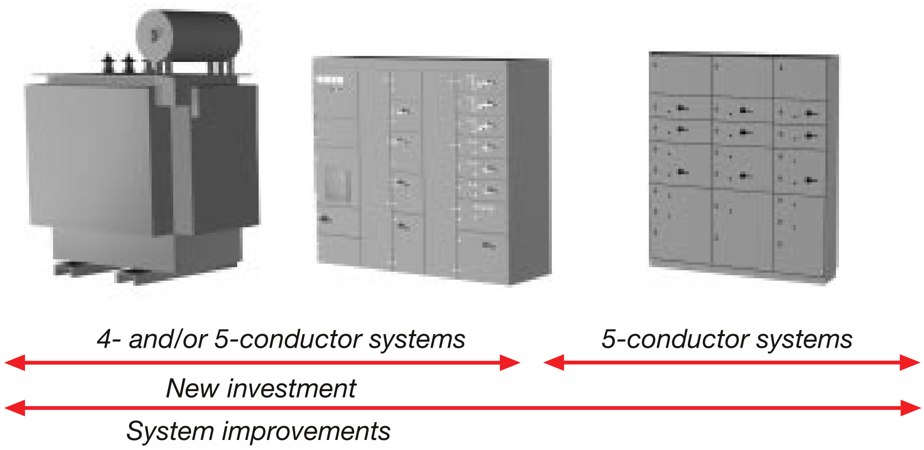
8.1 Filters for different currents

As a rule, the THF is chosen according to the nominal current of the feeding circuit. The basis for dimensioning the THF is the fact that it should withstand, in addition to the 150 Hz voltage, a 50 Hz neutral current, which is generated by a possible phase imbalance. Thus the filter is safe for use under any conditions.

Size of feeding fuse (A)	THF-filter quantity (pieces)	Recommended cable diameters for neutral conductors Cu.	
		Incoming - Outgoing cable	Connection between the filters
63	1 x THF 63N /NV	16 mm2	-
125	1 x THF 125N /NV	35 mm2	-
160	1 x THF 160N /NV	50 mm2	-
200	1 x THF 160N /NV + 1 x THF 63N	70 mm2	16 mm2
250	1 x THF 125NL /NLV + 1 x THF 125N	95 mm2	35 mm2
315	1 x THF 125NL /NLV + 1 x THF 125N + 1 x THF 63N	95 mm2	35 mm2 + 16 mm2
400	1 x THF 125NL/NLV + 2 x THF 125N	150 mm2	35 mm2
500	4 x THF 125N + THF 1BV1	185 mm2	35 mm2
630	5 x THF 125N + THF 1BV2	2 x 95 mm2	35 mm2
800	6 x THF 125N + THF 1 BV2	2 x 150 mm2	35 mm2

8.2 Filters in a distribution board

In a TN-S-system, filters are chosen according to the main fuse in a distribution board.



8.3 Dimensioning filters for a transformer circuit

The basis of dimensioning: The maximal asymmetrical current per phase is 50% of the rated current.

Transformer		THF filter
Pn/kVA	In/A	The number of mounting trays
315	460	2 x THF 125NP
		4 x THF 63NB/NP
500	720	3 x THF 125NP
		6 x THF 63NB/NP
630	900	3 x THF 125NP + 1 x THF 63NP
		7 x THF 63NB/NP
800	1150	4 x THF 125NP + 1 x THF 63NP
		9 x THF 63NB/NP
1000	1450	5 x THF 125NP + 1 x THF 63NP
		11 x THF 63NB/NP
1250	1800	7 x THF 125NP
		14 x THF 63NB/NP
1600	2300	9 x THF 125NP
		18 x THF 63NB/NP
2000	2900	11 x THF 125NP + 1 x THF 63NP
		23 x THF 63NB/NP

We reserve the right to alter specifications.

References

Sales and marketing of THFs began in Sweden at the end of 1994. Below is a list of sites where THFs have been installed.

Scania, Södertelje, autotruck factory
Gränges, Finspång, metal industry
Bofors, Karlskoga, arms industry
VME, Eslöv, loading machines
Greenhouses: Köping, Glimåkra, Ekerö, Intervekst/Norway
Huddinge Hospital
KREAB, Klippan, factory
Nokia, Tidaholm, repair shop
Göteborg Energi, Gothenburg, WC-games
EDET, Lilla Edet, paper industry
Health care school, Umeå
Schools: Vänamo, Gislaved
Town halls: Tranemo, O-vik
Karlstad, library
Ericsson, Karlstad, real estate
HP-flugger, Gothenburg, colour works
Såtenäs flytottilj, Lidköping, airfield
ASTRA, Södertälje, medicine industry
Volvo, Gothenburg

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- 50 Hz sähkö- ja magneettikenttien tekninen vähentäminen työympäristössä -seminaari 11/95
- Swedish Transmission Research Institute

If your network is haunted, THF will clean the current!

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