Input Power Quality for Speed Controllers

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Big Dutchman

1 Purpose

The purpose of this document is to highlight recommended best practices regarding mains power source sizing and installation of fans with speed controllers.

Installations with several barn houses on farms sharing the same power source need careful sizing and installation to get the full performance of the system.

Fans systems with these energy efficient speed controllers compared to traditional AC (on/off) fan motors, are not loading the mains supply in the same way, so when dimensioning power installation for speed controllers, other parameters than just total power load must be considered.

A speed controller is an electronic device with several internal measurement point to secure that none of the components are overloaded. A common reaction to an ‘out of range’ detection, is to reduce the output load by reducing the fan speed. If input power quality is not sufficient for the speed controller to operate safe, a reduction in fan speed must be expected.

The following important issues are explained this document.

- Harmonics
- Input supply requirements
- Mains supply wiring layout
- Transforms
- Generators

This document primarily focuses on 3-phase speed control types, but most of the recommendations can also be used to advantage for 1-phase speed controllers.

In this document, the term "speed controller" refers to Big Dutchman LPC Permanent Motor controllers and frequency converters (VFD’s).

Please note that Big Dutchman does not participate in or is responsible for dimensioning cabling topology, generators, transformers, or connection on the public power grid.

Therefore, the topics and technical details mentioned in this document are also only examples of parameters that the customer should discuss with those responsible for dimensioning the rest of the installation.

Contents

2 Harmonics

In large farmhouse installations the electronic load of the power source (consumer line, generator, or transformer) will be very high, if the fans installed are 100% speed controllers. For such a system it will be necessary to dimension the power source with harmonics in mind.

If the power system is not dimensioned for the load of electronics power devices, the following consequences may be experienced.

- Excessive temperature-rise in AC motors, cables, transformers, and generators.
- Electrical noise.
- Electronics malfunction. (LED light, climate computer and speed controllers)
- Accelerated aging of equipment.
- Tripping of circuit breakers.

What are harmonics?

In a normal alternating current (AC) power system, the current varies sinusoidally at a specific frequency, usually 50 or 60 Hz. When a linear electrical load is connected to the system, it draws a sinusoidal current at the same frequency as the voltage.

Loads not drawing the current at the fundamental frequency, will generate harmonics in the power system.

Harmonics are currents or voltages with frequencies that are integer multiples of the fundamental power frequency. If the fundamental power frequency is 50 Hz, then the 2nd harmonic is 100 Hz, the 3rd is 150 Hz, etc. (Figure 1).

Harmonic frequencies from the 3rd to the 25th is the most common range of frequencies measured in electrical power systems.

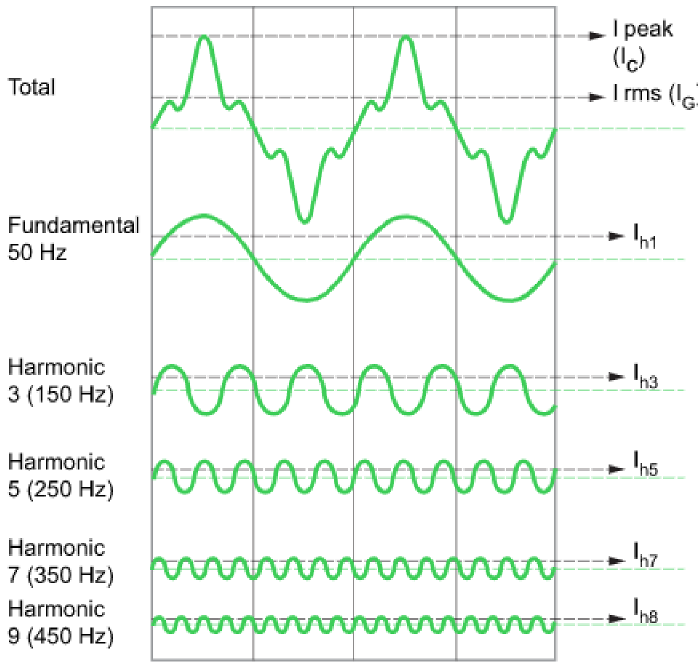


Figure 1

A “linear” load connected to an electric power system is defined as a load which draws current from the supply which is proportional to the applied voltage (for example, AC induction motors, incandescent lamps, heaters, etc.) Figure 2.

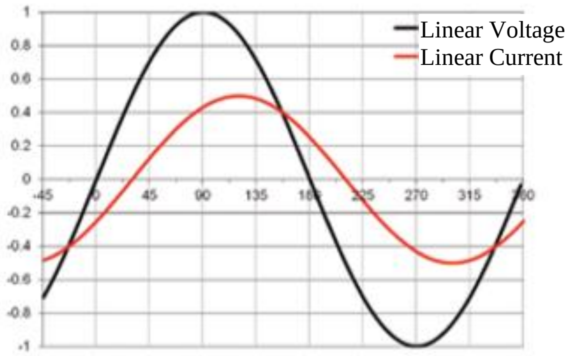


Figure 2

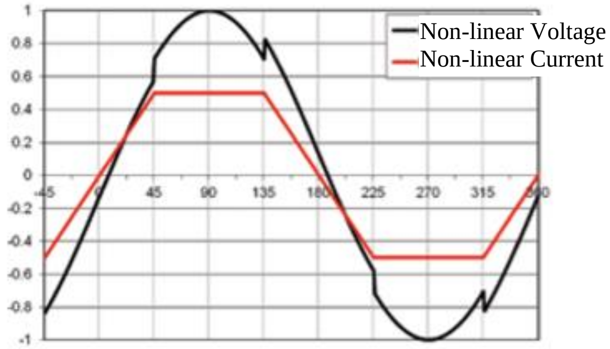


Figure 3

A load is considered "non-linear" if its impedance changes with the applied voltage (Figure 3).

Due to this changing impedance, the current drawn by the non-linear load is also non-linear, i.e. non-sinusoidal, in nature, even when it is connected to a sinusoidal power source. Non-linear loads can be computers, LED drives, variable frequency drives, etc.

Speed controllers like the LPC Controller for permanent magnet motors (PM motors) have been used in industrial applications for years because of their ability to provide precise process control. They have also become the standard method of controlling heating, ventilation and air-conditioning systems due to their efficient control resulting in significant energy savings.

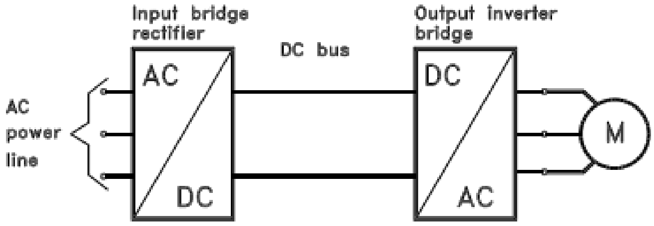
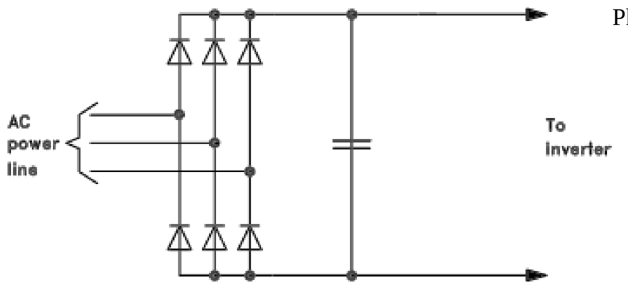


Figure 4

Most 3-phase speed controllers (Figure 4) use a bridge rectifier to convert the incoming AC voltage into a DC voltage. A DC bus capacitor is used to filter out the AC ripple. The inverter of the drive then converts the DC voltage into a controlled voltage and frequency for speed control of the motor.

The 3-phase rectifier bridge, shown in Figure 5, is a 6-pulse rectifier.



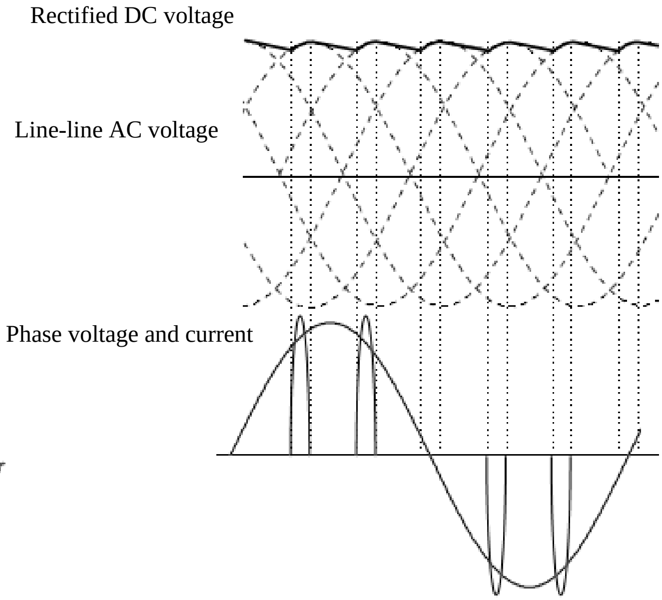


Figure 5

Figure 6

Even though this conversion to DC, results in a very efficient motor drive, it can cause problems with the AC power line, because of the way it draws AC current. Current will flow when any of the diodes are conducting, charging the capacitor. In this rectifier system (like the LPC controller hardware) this takes place 6 times at each 3-phase voltage cycle. As shown in Figure 6, this only happens for a very short period for each phase. To transfer the energy required by the motor in such a short period of time, the peak current must be high.

The input current is clearly seen to be non-sinusoidal. Such a current waveform has a high level of harmonic distortion.

3 *Input supply requirement*

Definitions used in fan documentation

Derating: The term "derating" or "derated performance" is used if the desired performance (fan speed) is not able to be met by the speed controller. The cause of speed controller derating can be high internal controller temperature, low input voltage, high motor load or combination of the mentioned issues. Combination of issues can be experienced with poor performing mains power installations.

Derating point: The level of voltage, current, voltage harmonics or temperature, where the speed controller is beginning to reduce the output load (RPM) to protect the internal controller components.

Controller Voltage: Controller voltages is the level of input voltage measured on the input terminals of the controller. 3-phase voltages are Phase – Phase, RMS values and single-phase voltages are Phase-Null, RMS values.

Nominal voltage: The voltage that the speed controller is designed for. The nominal controller voltage is used for most of the regulatory requirement tests.

Rated voltage: The nominal voltage and the voltage range in % in which the speed controller delivers full performance. Most fan speed controllers are 1x230 V, 3x230 V and 3x400 V. Voltage range are +/-10% on most controllers. The values can be found in the Technical info of the fan.

Operating voltage: The range of voltage where the speed controller still is operating. Outside the rated voltage range, full performance (fan RPM giving the airflow) cannot be expected. The derating point will depend on the load of the fan (sub-pressure in the house). Operating voltages are specific related to each fan system. The values can be found in the Technical Info of the fan.

Frequency: Nominal operating frequency. Speed controllers has an operating frequency range of 47 to 63 Hz.

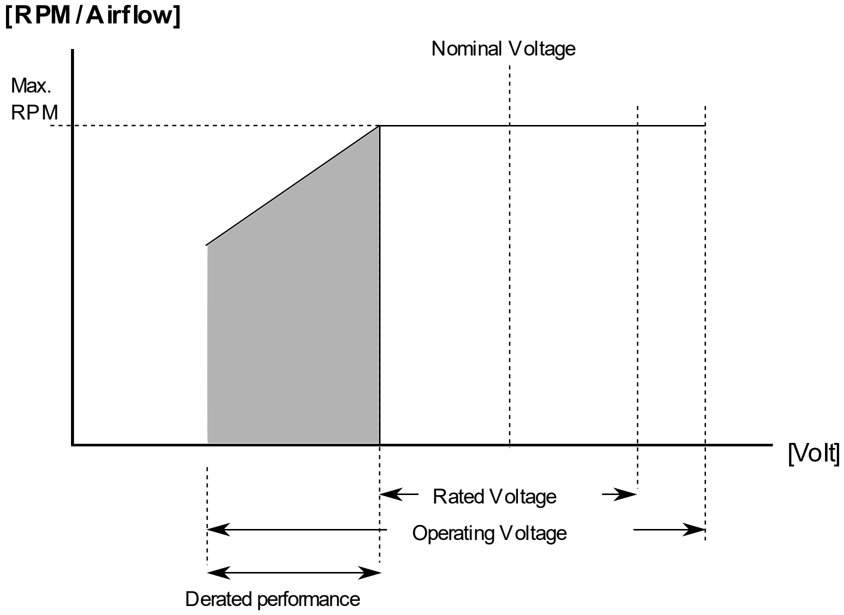
Leakage current to ground: Leakage to ground currents are measured at some dominant frequencies of the controller. The values can be found in the Technical info of the fan.

Max. current consumption: Maximum current at controller input at nominal voltage. If lower or higher voltages are present on the speed controller input terminals, the higher or lower input current must be calculated accordingly.

Max input power (P1): Maximum input power at nominal voltage.

CosPhi: CosPhi (or Power Factor) is the ratio between active power and apparent power $\frac{P[W]}{S[VA]}$ at maximum input power at nominal voltage.

Definitions of voltages:



4 Measuring Power Line Distortion

The acceptable level of voltage distortion depends on the sensitivity of the other equipment which is installed in the building. In order to compare the distortion levels, it is necessary to be able to quantitatively describe distortion. Harmonic analysis is used to provide this description.

There are two ways in which the results of this mathematical analysis can be expressed.

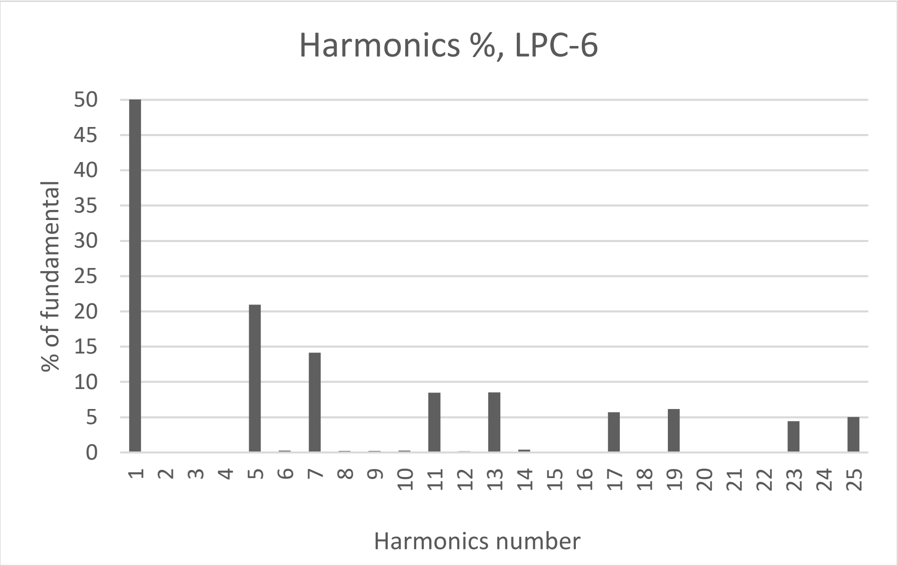
For a more simplified view, Total Harmonic Distortion (THD) is often used. As a percentage, this single number is calculated (Figure 7) by root, sum, square of the individual harmonics, relative to the value at the fundamental frequency (1. harmonics).

$$THD = \sqrt{\sum_{n=2}^{\infty} \left(\frac{H_n}{H_1} \right)^2} \cdot 100\%$$

Figure 7

The most detailed method describes the amplitude of each individual harmonic component, either in absolute units (such as volts) or as a percentage (Figure 8) of the fundamental component. With this, it is possible to determine the source of harmonic distortion. For example, in balanced electrical systems, the only harmonics that can be generated by symmetrical three phase loads are those that are not multiples of 2 or 3 (the 5th, 7th, 11th, 13th and similar harmonics). If a third harmonic is present in the system, it is probably the result of single-phase loads or phase imbalances. The detailed analysis of the harmonics in a system also helps when designing specific filters for solving harmonic distortion problems.

Harmonic currents measured on a LPC-6 at full load:



Harmonics	
number	%
1	100
3	0.1
5	20.8
7	14.2
9	0.1
11	8.5
13	8.5
15	0.1
17	5.7
19	6.2
21	0.1
23	4.4
25	5.0
	< 35%

Figure 8

The following Total Harmonic Distortion current values are the levels of harmonics in Big Dutchman speed controllers:

Controller Type	Nominal Voltage	THD%
1 Phase VFD	230Vac	< 4%
1 Phase LPC	230Vac	< 4%
3 Phase LPC	400Vac	<35%
3 Phase LPC	230Vac	<35%

Table 1.

The levels of harmonics in all Big Dutchman products with LPC controllers comply with:

- IEC 61000-3-2 Limits for harmonic current emissions. Class A for single-phase controllers
- IEC 61000-3-12 Limits for harmonic currents produced by equipment connected to public low-voltage systems. Standard document Table 5 for 3-phase controllers.

The requirement of the resulting controller voltage harmonics level in a farm installation is < 12% UTHD to secure operation without performance derating.

5 Dimensioning for electronics load

In planning of electrical installation of the equipment, it must be verified that the equipment is connected to an adequately dimensioned electrical power system. If necessary, through contact with the utility company or local electrical expert.

Power cables

Input power:

Different standards recommend dimensioning factors to minimize harmonics in power systems. These methods often result in "oversized" cables. However, technically this is only beneficial as it can reduce the operating temperature of the cable and as a result, the voltage drop in the cable is also reduced, thereby decreasing losses, and increasing transmission efficiency.

Voltage drop < 3% recommended.

Motor power:

The motor cables in the speed controller systems, are chosen to ensure regulatory compliancy regarding electromagnetic noise suppression to avoid disturbing electronical devices in the area.

Cables between speed controllers and motors are always shielded cable. The shielded motor cables must not be extended.

In a few products a longer cable can be ordered as a spare part. The cable must be installed instead of the original cable, following the instructions.

Conductor size conversion table.

AWG sizes	Diameter (d)		Area		Copper resistance		Aluminum resistance	
	inches	mm	kcmil (d² x 1000 inches)	mm²	ohms per 1000 feet	ohms per km	ohms per 1000 feet	ohms per km
(4/0) 0000	0.460	11.684	106	53	0.049	0.161	0.080	0.264
(3/0) 000	0.410	10.404	168	85.0	0.062	0.203	0.101	0.331
(2/0) 00	0.365	9.266	133	67.4	0.078	0.256	0.128	0.420
(1/0) 0	0.325	8.251	106	53.5	0.098	0.322	0.161	0.528
1	0.289	7.348	83.7	42.4	0.124	0.41	0.203	0.67
2	0.258	6.544	66.4	33.6	0.156	0.51	0.256	0.84
3	0.229	5.827	52.6	26.7	0.197	0.65	0.323	1.06
4	0.204	5.189	41.7	21.2	0.249	0.82	0.408	1.34
5	0.182	4.621	33.1	16.8	0.313	1.03	0.514	1.69
6	0.162	4.115	26.3	13.3	0.395	1.30	0.648	2.13
7	0.144	3.665	20.8	10.6	0.498	1.63	0.817	2.68
8	0.128	3.264	16.5	8.37	0.628	2.06	1.030	3.38
9	0.114	2.906	13.1	6.63	0.792	2.60	1.300	4.27
10	0.102	2.588	10.4	5.26	0.999	3.28	1.640	5.38
11	0.091	2.304	8.23	4.17	1.260	4.13	2.070	6.79
12	0.081	2.053	6.53	3.31	1.588	5.21	2.610	8.56
13	0.072	1.829	5.18	2.63	2.003	6.57	3.290	10.79
14	0.064	1.628	4.11	2.08	2.525	8.28	4.140	13.58

Transformer

Harmonics-rated Distribution Transformers known as K-factor transformers and are specifically designed to cope with the excess heating problem, caused by the presence of high level circulating harmonic currents. The thermal and neutral connections in the transformer are often oversized to accommodate the harmonic loads.

Using a K-factor transformer are often more economical than a derated oversized transformer.

This table shows some “rule of thumb” for determining K-factors.

Electronic, nonlinear load (Speed controllers)	Electrical, linear load (AC Induction motors)	UL K-rating
0%	100%	K-1
25%	75%	K-4
50%	50%	K-9
75%	25%	K-13
100%	0%	K-20

Generator

Like the transformer, also the generator must be dimensioned properly. Large current harmonics (ITHD) will also here, depending on the generator reactance (Xd’’), give some voltage harmonics (UTHD), especially if the amount of non-linear load is high. High level of voltage harmonics will affect the fan system performance.

To avoid performance problems with a high level of nonlinear loads, generators with low sub transient reactance (Xd’’) are recommended. Requirement for low Xd’’ to keep a low UTHD, can give a higher KVA generator, than if all load was linear.

Generator sizing, in nonlinear loaded supplies, are not only based on a simple sum of loads. Generator suppliers can calculate required sizing of the generator, based on load share and size (linear and nonlinear) and requirement of max. UTHD.

Filters

In some installations and in regions with special requirements, it may be necessary to install harmonics filters in the supply line for the speed controllers. Filters can be standard filters or custom-designed filter for the exact installation from measurements onsite, designed to suppress harmonics. Filters can be active or passive depending on filtering requirements.

Line reactors

A line reactor is an inductor, a coil of wire, that forms a magnetic field as current flows through it. The magnetic field limits the rate of rise of the current, which reduces harmonics, making it more sinusoidal and helps reducing voltage THD on the supply line. The lower harmonic level improves system performance and reliability.

Transient protection

The input on the speed controllers are Surge protected according to EN 61000-4-5, +/- 4 kV.

In areas with frequent large voltage transient i.e. lightning strikes, additional protection (line arrestor) is recommended.

In systems with switching between line power and generator power, it must be verified that transients in switching, do not exceeds maximum input voltage of the products.

Grounding

It is important that the grounding of the power system is efficient and complies with the local regulations.

It is important that shielding of the motor cable is efficiently connected to the motor and the speed controller frame, to minimize disturbances of other equipment in the buildings.

The grounding system allows all equipment to have the same reference voltage. The electronic power supply in electronic equipment uses the frame of the equipment as the reference point. This is where the AC equipment grounding conductor and the electronic equipment grounding circuit come together. This helps the installed electronic equipment operation and helps prevent the flow of disruptive currents in communication lines, conduits, shields, and other connections.

Phase voltage balance

An unbalanced three-phase system can cause three-phase motors and other three-phase loads to experience poor performance or premature failure because of the following:

- Mechanical stresses in AC motors due to lower than normal torque output.
- Higher than normal current in motors and three-phase rectifiers.

Voltage unbalance at the input terminals causes high current unbalance.

Unbalance can occur at any point throughout the electrical power system. Loads should be equally divided across each phase. Should one phase become too heavily loaded in comparison to others, voltage will be lower on that phase.

Transformers and three-phase motors and electronic equipment may run hotter, be unusually noisy, vibrate excessively (AC motors), and suffer premature failure.

Level of unbalance are following IEC61800-3:

$$Interphase\ voltage\ unbalance\ (\%) = \frac{Max.voltage - Min.\ voltage}{3\ phase\ average\ voltage} \times 67$$

Interphase voltage unbalance on 3 phase LPC controllers $\underline{\leq 3\%}$

Control wires

The low voltage analog control wiring (0-10 V DC, 24 V DC start/stop and fan reverse etc.) from the speed controller, should be separated from any high voltage wiring (above 50 V DC) and if it must cross any high voltage wires (above 50 V DC) crossing at a 90° angle are recommended. When running parallel with any high-voltage wires, they should be spaced as far away as it is permitted to prevent any EMI interference. To avoid using shielded cables, the above-mentioned guidelines should be followed.

6 *Mains supply*

Cable layout

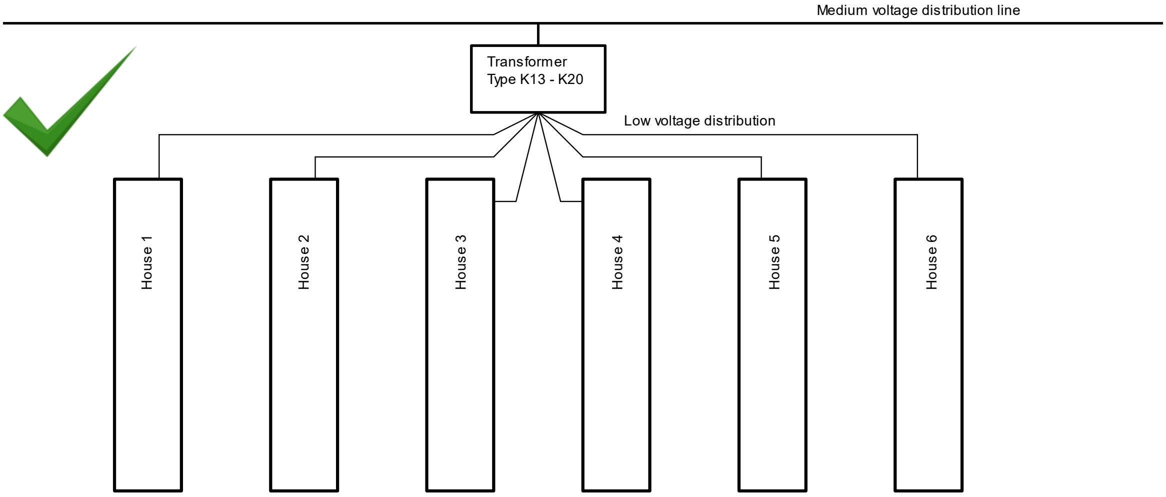
In installations with large amount of speed controllers and where the speed controllers are the dominating power consumer on a transformer, care should be taken to wiring of the farmhouses.

A method to reduce speed controller harmonic influence on each other, is to wire a group (i.e. each house) separate to the transformer / generator connection point.

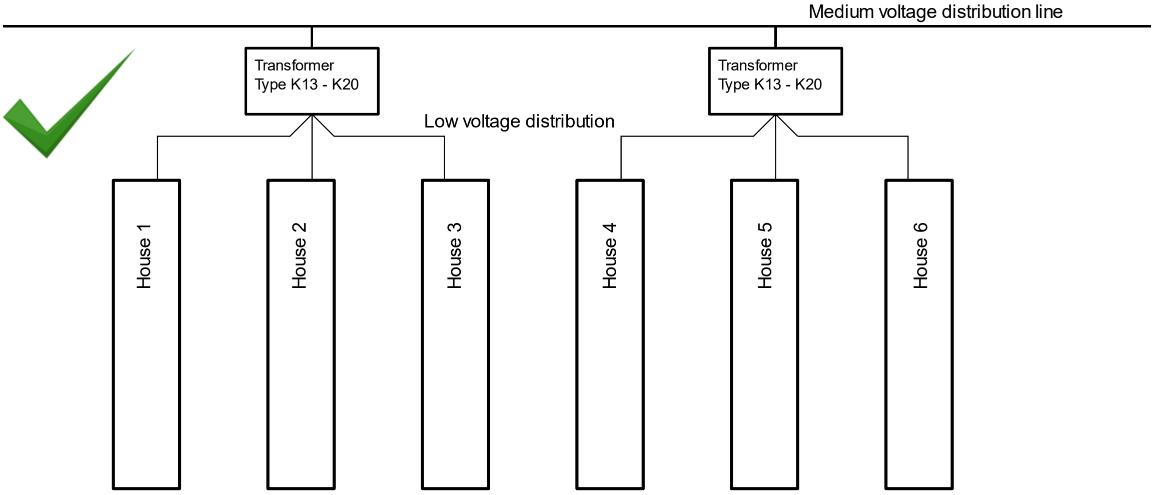
Preferred wiring is when all houses are separately wired to a common connection point at the power source like Example 1 and 2.

If wiring is done like example 3, there will be a high risk of speed controllers harmonics, disturbing each other, with risk of derated ventilation performance.

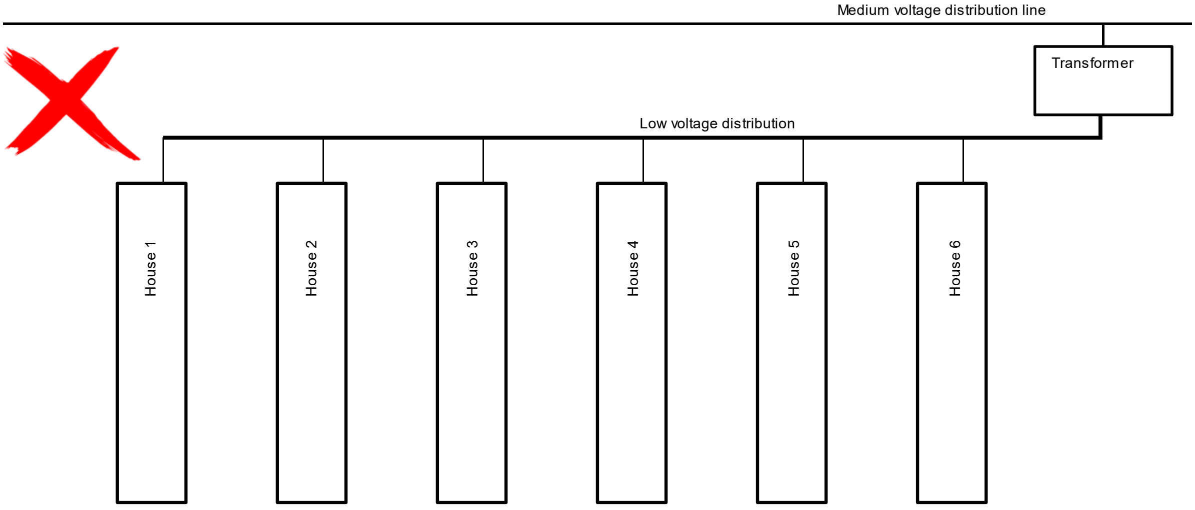
Example 1. **Common point** layout gives longer but thinner wires than busbar connected wires.



Example 2. **Common point** with multi transformer layout. Shorter wires, but more (smaller) transformers.



Example 3. **Busbar** connected requires highly over-dimensioned low voltage distribution line, to reduce house to house supply harmonics impact, with high risk of reduced performance. Wiring type are not preferred!



7 Residual current

It is important to follow local regulations regarding installation of protection against residual current.

Protection against residual currents are mainly to protect people and animals from electric shock.

RCD's (Residual Current Devices) with different breaking characteristics can be used for protection. The device is connected on the supply line to measure small current flowing to Earth. In case of excessive current flow to earth, the device breaks the power line.

There are two types of leakage currents: ac leakage and dc leakage.

AC leakage current is caused by a parallel combination of capacitance and dc resistance between a voltage source (ac line) and the grounded conductive parts of the equipment.

DC leakage current caused by dc resistance, usually is insignificant compared to the ac impedance of various parallel capacitances. The capacitance may be intentional (such as in EMI filter capacitors) or unintentional.

Examples of unintentional capacitances are spacings on printed circuit boards, insulations between semiconductors and grounded heat sinks, capacitance between cable wires, windings, and housing on motors.

In speed controllers the internal circuit is built in a way that dc leakage cannot be avoided in circuit failure situations.

RCD of type B can handle dc leakage current. The RCD type B is recommended to protect the installation of speed controllers against residual currents.

LPC -6 controller 3x400 V residual current:

Frequency	Current [mA] RMS
50 Hz	1
500 Hz	30
1 kHz	5
4 kHz	34
8 kHz	42
12 kHz	2
24 kHz	6
Inrush current (< 4uSec.)	< 20 A

Different types of common used RCD's.

RCD Type	AC	A	F	B	B+	
Symbols on RCD					kHz	
Currents sensitivety	AC	AC and pulsating DC	AC and pulsating DC	AC, pulsating DC and flat DC	AC, pulsating DC and flat DC	
Standard	IEC / EN 61008 IEC / EN 61008	IEC / EN 61008 IEC / EN 61009	IEC / EN 62423	IEC / EN 62423	VDE 0664-400	
Residual current waveform						**Tripping currents IΔ = marking current**
	•	•	•	•	•	0,5 to 1,0 •IΔ
		•	•	•	•	0,35 to 1,4 •IΔ
		•	•	•	•	0,25 to 1,4 •IΔ (90°) 0,11 to 1,4 •IΔ (135°)
		•	•	•	•	max. 1,4•IΔ + 6mA DC (+ 10mA for F type)
			•	•	•	0,5 to 1,4 •IΔ
				•	•	0,5 to 2,0 •IΔ
Frequency range	< 1kHz	< 1kHz	< 1kHz	<1kHz	< 20kHz	

Because of the different tripping levels and tollerences on RCD products, the RCD supplier must be consulted to decide type, size and number of Fans on a RCD.

The residual current from a non-linear device will be frequency dependent (Figure 9). The frequency content of the residual current must also be taken into consideration when dimensioning RCD size and number of products on one RCD.

The RCD must be dimensioned according to type, recommended tripping current factor and local authorities / insurance regulation.

In industrial installations an RCD of 300 mA type B are often used.

Figure 9 shows the tripping current and frequency relationship of an RCD type B.

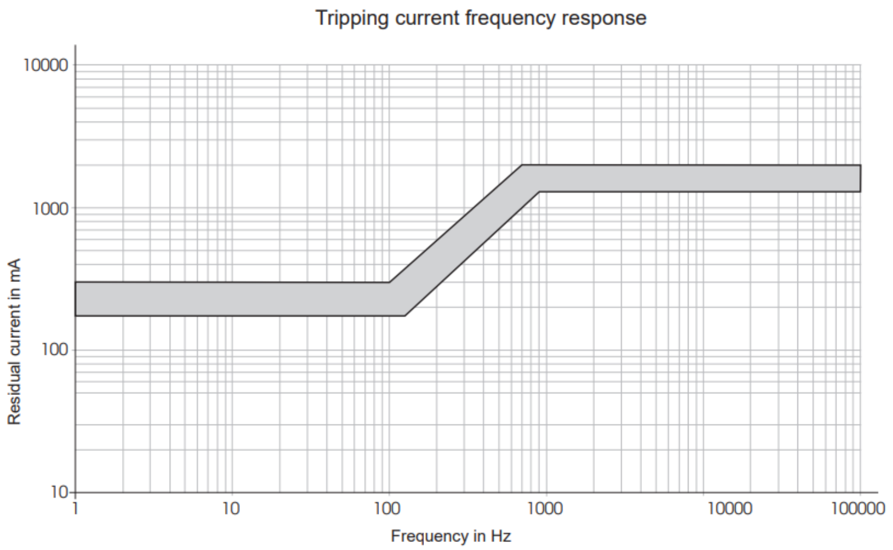


Figure 9

8 Installation of speed controller

Ingress protection

To protect the electronics circuit from dust, moisture and water the enclosure of the speed controllers is following IP 65 protection class. Even small amounts of water inside the controller will damage the circuit permanently.

To prevent water from running into the speed controller via cables and cable glands, the cabling must be carried out, so that it can stand water around the cable in the gasket of the cable glands. The recommended mounting is shown in Figure 10

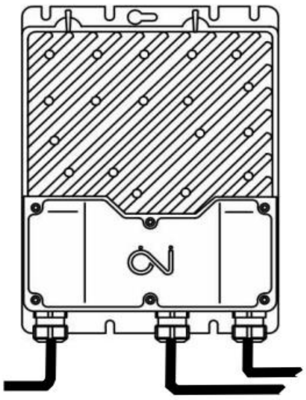


Figure 10

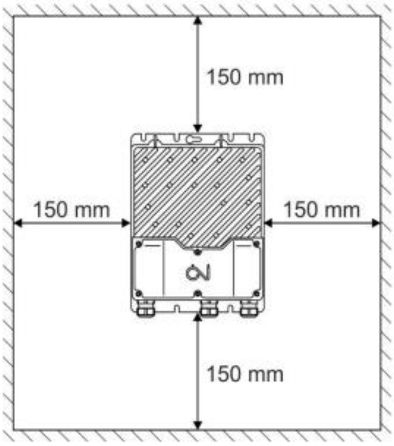


Figure 11

If cables and wire tubes come from above the speed controller, secure that no water can run down inside the cable / cable tube and into the speed controller.

In wire tubes, draining holes in the tubes are important to prevent moisture accumulation, and risk of water flowing into the speed controller.

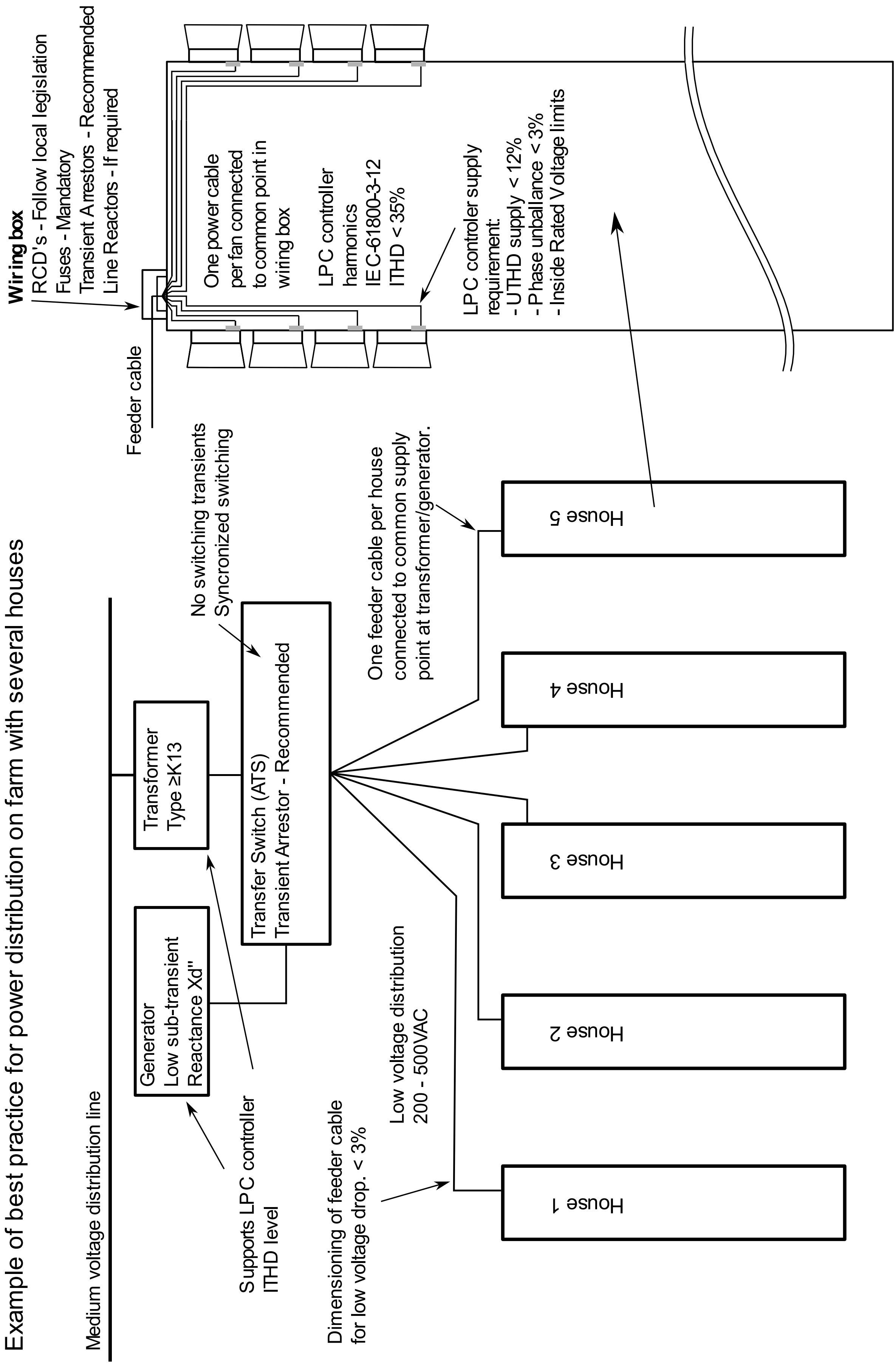
Ensure that all 6 screws in the cover are tightened and that the plastic cover gasket is properly in contact with the aluminum housing.

Mounting

The speed controller enclosure is dependent on some airflow, to keep it cooled to a safe operating temperature. Figure 11 shows the recommended distances to another object.

If the controller is built in a box or exposed to direct sunlight, performance derating can be expected, and the lifetime of the speed controller will be considerable shortened.

9 Example


Example of best practice for power distribution on farm with several houses
Medium voltage distribution line
Generator
Low sub-transient
Reactance Xd''
Transformer
Type ≥K13
Transfer Switch (ATS)
Transient Arrestor - Recommended
No switching transients
Syncronized switching
Supports LPC controller
ITHD level
Dimensioning of feeder cable
for low voltage drop. < 3%
Low voltage distribution
200 - 500VAC
One feeder cable per house
connected to common supply
point at transformer/generator.
House 1
House 2
House 3
House 4
House 5
Feeder cable
Wiring box
RCD's - Follow local legislation
Fuses - Mandatory
Transient Arrestors - Recommended
Line Reactors - If required
One power cable
per fan connected
to common point in
wiring box
LPC controller
harmonics
IEC-61800-3-12
ITHD < 35%
LPC controler supply
requirement:
- UTHD supply < 12%
- Phase unballance < 3%
- Inside Rated Voltage limits

10 Installation requirement checklist

- ❑ Confirmation from Power Utility Compagnie for delivery of required power for the farm, 24 hour/day, 365 days/year.
- ❑ Transformer type and size are chosen to deliver required power for the installed product types.
- ❑ Generator type and size are chosen to deliver required power for the installed product types.
- ❑ Wiring plan are made according to recommended layout.
- ❑ Wire dimensions are chosen according to required load type and size.
- ❑ Filters and protection devices are installed.
- ❑ Local / region regulations are followed regarding installation requirements.
- ❑ Speed controllers and fans are mounted according to recommendations.

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