Nidec
Power

TECHNICAL NOTE

TN03

SIZING WITH DISTORTING LOADS

Aim: To select an alternator from the product catalogues in the context of an application with distorting loads.

REMINDERS

• EXAMPLES OF DISTORTING LOADS

Rectifiers, computers, inverters, soft starters, variable speed drives, gas or fluorescent lighting, welding.

• SPECIFIC APPLICATION FEATURES

Distorting loads, also known as non-linear loads, generate harmonics in the current waveform.

• HARMONICS HAVE TWO MAJOR DISADVANTAGES

- They distort the generator voltage waveform, which can lead to unstable operation of the whole unit (generator set and load converters) and also generate interference on all the supplied loads.
- Harmonic currents, which cause additional losses and can result in harmful alternator overheating.

SIZING ALTERNATORS

In general, when the total power of the distorting loads represents less than 50% of the total power, the alternator does not need to be derated and the alternator size is only determined in relation to the total power.
If the distorting loads are 50% or more :
-check that the total power (distorting load + nondistorting load) is less than 95%of the isolated alternator rated power (see catalogue). This empirical rule takes account of the additional heating caused by the distorting load harmonic currents.
- take the type of load into account.

Depending on the available data, there are three likely hypotheses:

• HYPOTHESIS 1 (EMPIRICAL)

The type of distorting load is known, but neither the current harmonic spectrum, nor the max. permissible voltage distortion is available. In this case, the approximate size can be determined by referring to table A (Appendix A).

Minimum input data to be supplied by the customer
1- List of distorting loads, specifying the type (drive, inverter, 6-pulse or 12-pulse rectifier, ...)
2- Non-linear Snl input power in kVA for each dis-torting load
3- Total power in kVA (distorting loads + non-distorting loads)

Alternator sizing

a) The list of distorting loads allows the sizing criterion corresponding to each type of distorting load to be found in table A.

b) If all the distorting loads are the same type, add together all the Snl powers of each distorting load and apply the sizing criterion in point a), for the total power thus determined.

c) If the distorting loads are different types, select the alternator as follows :

- for loads corresponding to one of the first four cases in table A in Appendix A, the alternator should verify the sizing criterion corresponding to each Snl power given.
- for loads which impose a limit reactance value X"d (all other cases in table A), an alternator can be determined, approximately, by calculating the weighted average value of X"d.

Example application

Example data

The load consists of:

- a 120 kVA/400 V/50 Hz frequency inverter
- a 60 kVA/400 V/50 Hz 6-pulse rectifier

Example resolution

- X"d = 12% for the drive
- X"d = 10% for the rectifier

The total power is therefore : Pt = 120 + 60 = 180 kVA

and average X"d = (12 x 120 + 10 x 60) / 180 = 11.3%.

From this we can deduce that the alternator thus selected must have an unsaturated reactance X"d < 11.3% at 180 kVA.

Checking the result

To check this condition, in the catalogue we can find the LSA 46.3 S5/250 kVA, for which the unsaturated reactance X"d to be calculated is 15% at 250 kVA.

Thus at 180 kVA the reactance of the LSA 46.3 S5 is : 15 x 180/250 = 10.8% which is less than 11.3% as calculated earlier.

Don‘t forget to check that the alternator rated power determined at points b or c is at least as high as the total power of the distorting loads and non-distorting loads. If this is not the case, select an alternator with a higher power and check that the new alternator selected does not downgrade the reactance applied to the power of the distorting load.

• HYPOTHESIS 2

More accurate calculation with information about the harmonics

This hypothesis considers the case of identical distorting loads, with the same current harmonic spectrum.

Minimum input data

1- Total power in kVA (linear loads + non-linear loads)

2- Total Snl input power, in kVA, of the non-linear loads

3- Analysis of current harmonics reinjected into the alternator

4- Max. permissible total harmonic voltage distortion THVD as a %

If the THVD is not known, please refer to table C in Appendix A

Alternator sizing

a)Initially the permissible reactance, unsaturated X"d as a %, should be determined by calculating it, using the following formula this time:

$$X"d = \frac{THVD}{Kh}$$

where:

- THVD is given by the customer or by table C in Appendix A.
- Kh is the factor calculated from the current harmonic spectrum (see example in table B in Appendix A).

$$Kh = \frac{\sqrt{\Sigma\,(N \times Ih)2}}{100}$$

b) From the catalogue, select an alternator whose reactance X"d is unsaturated for the Snl power (see definition in Appendix A) and equal to or less than the value determined in a.

c) Take care not to forget to check that the alternator rated power determined at b is at least as high as the total power of the linear loads and non-linear loads.

● HYPOTHESIS 3

The linear loads are not identical and have harmonic spectra that are different but known.

In this case, it is necessary to combine the harmonic currents of the various loads expressed in amps, in order to obtain an equivalent global spectrum for the whole unit.

The harmonic equivalent to number n will be equal to the square root of the sum of the squares of the number n harmonics of each load.

The spectrum thus obtained should be associated with a power rating equivalent to all the non-linear loads, calculated by the sum of the non-linear load powers expressed in kVA.

Application example

Example data

Distorting load consisting of 2 uninterruptible power supplies (UPS) of 320 kVA and 60 kVA 400V/50 Hz, whose harmonic spectrum has been communicated by the customer (see Appendix B).

Example resolution

From the harmonics as a %, the value of each harmonic can be deduced in amps, by multiplying the ratio as a % by the value in amps of harmonic current H1 (see calculation of H1 current in amps in Appendix B).

The equivalent harmonic current, for number n, is obtained by taking the square root of the sum of the squares of the number n harmonics of each load.

The equivalent spectrum as a % is obtained by multiplying by 100 the ratio of each harmonic thus obtained with number 1 harmonic current (see Appendix B).

The power corresponding to the new analysis thus calculated is:

Snl = 320 + 60 = 380kVA

With this power and the equivalent harmonic spectrum, the sizing calculation is applied to hypothesis 2.

APPENDIX A

Definitions

Snl: distorting load input power in kVA

Sn: alternator rated power indicated in the catalogue

X"dn: reactance at the alternator Sn rated power available in the catalogue (saturated subtransient directaxis reactance)

X"d: unsaturated reactance

Calculation of unsaturated X"d

For a non-distorting load input power in kVA:

$$X\text{"}d\ unsaturated = X\text{"}dn\ x\ k\ x \left(\frac{Snl}{Sn}\right)$$

With values of k being :

Frame size	k
LSA 40	2
LSA 42.3	2
LSA 43.2	2
LSA 44.2	1.66
LSA 44.3	1.66
LSA 46.2	1.66
LSA 46.3	1.25
LSA 47.2	1.43
LSA 49.1	1.25
LSA 49.3	1.25
LSA 50.2	1.176
LSA 51.2	1.176
LSA 52.3	1.176

Tabble A

Load type	Sizing criteria
Fluorescent lighting	No derating with our std range pitch 2/3 with full pitch or 5/6 pitch: lighting power ≤ 50% alternator rated power
Gas lamp lighting	Input data : Kvar → Reactive power of lamp correction capacitors Criterion : the alternator Sn (kva) should be ≥ 5 x Kvar
Welding	Input data : load impact on voltage build-up (in kVA) Criterion : the alternator is calculated for DU(%) ≤ 15%, cos phi = 0.6 for the load impact
Diode rectifier	Criterion : rectifier input power in kVA ≤ alternator Class F power
12-pulse rectifier	Criterion : check that unsaturated X"d ≤ 12% (calculated for the rectifier input power in kVA)
6-pulse rectifier	Unsaturated X"d ≤ 10% (calculated for the rectifier input power in kVA)
3-pulse rectifier	Unsaturated X"d ≤ 7% (calculated for the rectifier input power in kVA)
D.C. drive	Unsaturated X"d ≤ 7% (calculated for the drive input power in kVA)
Frequency inverter	Unsaturated X"d ≤ 12% (calculated for the drive input power in kVA)
Electronic starter	Unsaturated X"d ≤ 12% (calculated for the starter input power in kVA)
Inverter	Unsaturated X"d ≤ 10% (calculated for the inverter input power in kVA)

Table B

N (current harmonic number)	Ih (individual harmonics as a %)	$(N \times Ih)^2$
5	17.5	7656.3
7	11	5929
11	4.5	2450.3
13	3	1521
17	1.5	650.3
19	1.3	610.1
23	0.8	338.6
25	0.7	306.3
29	0.4	134.6
31	0.3	86.5
35	0.2	49
37	0.2	54.8
41	0.15	37.8
43	0.15	41.6
		$H = \sum (N \times Ih)^2 = 19865.9$

where $Kh = (\sqrt{H})/100 = 1.4$

Table C

Load	THVD	Typical application
6 diodes rectifier	Any	Traction, variable speed cranes
6 pulse thyristors rectifier	25%	TELECOMS
6 diodes rectifier + chopper	Any	TELECOMS
12 pulse thyristors rectifier	25%	TELECOMS
6 pulse inverter	15%	UPS, variable speed drive
6 pulse four quadrant DC drive	15%	Cranes, D.C. variable speed drives

These values are high enough to ensure that the distorting load and the alternator work correctly but may not be suitable for other uses.

APPENDIX B

320 kVA uninterruptible power supply

$$Ineff = \frac{(320 \text{ x } 1000)}{(400 \text{ x} \sqrt{3})} = 461.9 \ A$$

Harmonics	H1	H3	H5	H7	H11	H13	H23	H35	H37
%	100	0.2	2.1	0.6	4.3	1.5	1.5	0.6	0.4

Calculation of the fundamental current (H1 harmonic)

General formula:

$$\frac{Ifund}{Ineff} = \frac{100}{\sqrt{H1^2 + H3^2 + H5^2 + \cdots H37^2}}$$

Specific example:

$$\frac{Ifund}{Ineff} = \frac{100}{\sqrt{10028.4}} \qquad \frac{Ifund}{Ineff} = \frac{100}{100.1} = 1$$

$$Ifund = 1 \text{ x } 461.9 = 461.9 \ A$$

Calculation of harmonic currents Ih in amps

Harmonics	Ih = Ifund*H(%)	Ih²
H1	461.2	212723.9
H3	0.9	0.9
H5	9.7	93.8
H7	2.8	7.7
H11	19.8	393.3
H13	7.1	49.8
H23	6.9	47.2
H35	2.8	7.7
H37	1.9	3.4

60 kVA uninterruptible power supply

$$Ineff = \frac{(60 \text{ x } 1000)}{(400 * \sqrt{3})} = 86.6 \ A$$

Harmonics	H1	H3	H5	H7	H11	H13	H23	H25	H27	H35	H37
%	100	1	3	1	7	2.5	2.5	1	1	1	1

$$\frac{Ifund}{Ineff} = 1$$

$$Ifund = 1 \text{ x } 86.6 = 86.6 \ A$$