Care should be taken to ensure that the transformer is selected appropriately for the range of ambient temperatures the application space will present.

In most cases, the supplier of the transformer will define the appropriate ambient temperature for the product in most conditions like storage, transportation, or operation. The selection of the transformer should consider and follow the *manufacturer*'s recommendations.

For safety, apply IEC 61800-5-1.

5.3.6.2.4 Impedance

5.3.6.2.4.1 General

The input transformer impedances should be coordinated in regard to harmonic emission and fault current requirements; typically, the impedance is in the 6 % to 12 % range according to IEC 60076 (all parts).

5.3.6.2.4.2 Commutating reactance

Commutating reactance is an important parameter for line commutated *converter*s. Measurement methods for commutating reactance are given IEC 61378-1.

5.3.6.2.4.3 Impedance with self-commutated *converter*s

Commutating reactance has less impact on the performance of self-commutated *converter*s. However, transformer impedance may be important to limit harmonic currents or fault currents. For self-commutated *converter*s, the impedance is usually taken to be the *short-circuit* transformer impedance measured in standard transformer tests. See IEC 60076-1. Measuring the *short-circuit* impedance at the frequency of interest may also be advisable.

5.3.6.2.5 Common mode and DC voltages

Some types of *converter*s can impose voltage offsets on input or output transformers. Two common problems caused by voltage offsets are:

– increased insulation stress due to common mode voltages or unusual voltage conditions;
– core saturation due to DC voltage or DC current magnetization.

These problems should be considered and addressed in the properly designed PDS.

Apply IEC TS 61800-8.

5.3.6.2.6 Specific considerations

5.3.6.2.6.1 Cooling systems

See IEC 60076-1.

5.3.6.2.6.2 Voltage accuracy

Apply IEC 60076 (all parts).

5.3.6.2.6.3 Parallel connection of bridges

Care should be taken when considering the case of parallel connection of bridges (accuracy of no-load voltages, phase shift, short-circuit impedance of each secondary winding).

5.3.6.2.6.4 Shielding between primary and secondary winding

An electrostatic shield is recommended in order to prevent high-voltage transients being transferred to the secondary due to capacitive coupling. The shield also has an EMC effect on the common mode impedance for conducted disturbances. For both reasons, the inductance of the shield connection to earth should be low.

For full EMC considerations, apply IEC 61800-3.

5.3.6.2.6.5 *Short-circuit* requirements

Existing *BDM/CDM* designs create an increased possibility of *short-circuit* events on the secondary of a transformer. This is due to the usage of power electronic circuits fed by the secondary of the transformer. These power electronic circuits are most likely to fail in a shorted condition at the start of the failure. Care should be taken to ensure that the transformer used is constructed to tolerate these occurrences, or additional protection should be provided to limit the energy to within acceptable levels during the *short-circuit* events.

5.3.6.2.7 Overvoltages

Additional overvoltage limitation may be required to be provided for main power supply transformers (for example transient energy absorption as lightning arresters (LA)). Care should be taken to ensure that it is addressed through construction or additional protection when required.

The energy of the non-repetitive transients caused by no-load switching of the main transformer feeding the *converter* assembly is related to the transformer magnetizing energy E. Under the assumption of a sinusoidal magnetizing current, the energy stored in the magnetizing impedance of the transformer can be calculated by the following equation:

$$E(J) = \frac{i_{\mathrm{mpu}}}{4 \times \pi \times f_{\mathrm{LN}}} \times S_{\mathrm{N}}$$

where

i_{mpu} is the magnetizing current, referred to the rated transformer current (p.u.);

f_{LN} is the rated frequency (Hz);

S_{N} is the apparent power of the transformer (VA).

5.3.6.3 *Motor*

5.3.6.3.1 General

It is important to ensure that the *motor* selected for the PDS is adequate for the intended application, including all modes of operations, environmental conditions, EMC, energy *efficiency*, and safety considerations. For operations and environmental conditions apply IEC 60034 (all parts), for EMC apply IEC 61800-3, for energy *efficiency* apply IEC 61800-9-2, and for safety apply IEC 61800-5-1. *Motor* construction can consist of general-purpose standard design as well as special application orientated. In addition to standard *motor* designs, new technologies including permanent magnet *motor*s and other special solutions are also considered.

In this field of application, many different types of *motor*s exist. Most are induction and synchronous *motor*s. The number of phases is typically three or six.

Requirements for commonly used *motor*s are covered by the relevant product standard of the IEC 60034 series. Subclause 5.3.6.3 considers the integration and interfacing of the *motor* as a part of the PDS.

5.3.6.3.2 Design considerations

Generally, the design of a *motor* should follow IEC 60034 (all parts) or nationally recognized equivalent.

Special attention is required because of the *speed* dependency on heat transfer of self-ventilated cooling systems and additional harmonic losses in *inverter* fed *motor* operation (see IEC 60034-25).

Unless otherwise specified, ambient and cooling temperatures, thermal class and temperature rise of the motor winding insulation system in *inverter* fed conditions should be in accordance with IEC 60034-1.

For *motor* energy *efficiency*, see IEC 60034-30 (all parts) and guidance from IEC 60034-1, for PDS energy *efficiency* IEC 61800-9-2, and for safety of the PDS see IEC 61800-5-1.

5.3.6.3.3 Performance requirements

5.3.6.3.3.1 General

The performance requirements of the motor should be selected to meet the requirements of the application. These requirements will commonly include voltage, current, frequency, speed, torque, inertia, environmental, etc.

In the case of 3-phase *motor*s, occasionally a direct bypass to the line-side of the *BDM/CDM* may be required. A *motor* partial-winding operation in the case of a winding system with a multiple of 3 phases is also conceivable.

If performance and rating conditions for such a bypass operation are required, this should be requested by the *customer* and have clear detail provided to the supplier. If selected, the following detail is provided, but not considered an exhaustive list.

– necessary starting performance;
– eventually different *rated torque*.

For additional performance information, apply IEC 60034 (all parts).

5.3.6.3.3.2 *Motor* input ratings

The parameters for the input to the *motor* fed from a *BDM/CDM* are important in the properly designed PDS. Information regarding *motor* rating, operating frequency and voltage ranges can be found in IEC TS 61800-8.

Additional important information is the *motor* current which should be considered at rated *motor* voltage, base *speed* and rated PDS load. The following information is likely required for all applications:

– the total RMS current of the *motor* (I_{AN});
– the fundamental and the relevant harmonic current spectrum of the *motor* may be required at the specified or typical output impedance (including *motor* and, if any, transformer and filters); the information specific to the *motor*, transformers and filters, if any.

The *system integrator* should consider the following when purchasing the *motor* to ensure it will work within the PDS design:

– the excitation current of the motor, if any;
– the auxiliary supply.

NOTE For detail on the additional losses due to the higher frequency current harmonics, see IEC 61800-9-2.

5.3.6.3.3.3 *Motor* output ratings

See 5.3.6.3.3.1.

5.3.6.3.4 Mechanical system integration requirements

5.3.6.3.4.1 Protection against destructive shaft voltages or bearing currents

The *system integrator* should determine whether a *motor* with bearing insulation at the non-driven end is required and supplied accordingly.

In addition to the recommended earthing practices, other preventive measures may be necessary. They are especially needed when high frequency components exist in the *motor* voltage, including common mode voltages, caused by the *converter*. Some additional insulation measures include:

– the complete isolation of the *motor* shaft from the motor frame by the insulation of all the *motor* bearings in combination with a suitable earthing of the shaft to exclude electrostatic charging effects;
– an insulated coupling used to connect the driven equipment.

Filtering can also be considered, according to the topology of the *inverter*, particularly in the case of PWM voltage source *inverter*s by means of:

– common mode filters;
– dv/dt limitation;
– sinusoidal filter.

The *system integrator* should give advice, if additional measures are required.

See IEC TS 61800-8 for guidance.

5.3.6.3.4.2 *Motor*-vibrations and lateral resonance

Unless otherwise specified, the permitted limits of vibration severity and method of measurement should be as defined in IEC 60034-14.

In this context, the correct *motor* fastening (foundation, mechanical string alignment and coupling) is a consideration of the *system integrator*, which will need to coordinate this with the *manufacturer* of the driven equipment and *motor*. Special attention should be given to the lateral resonance frequencies of the whole mechanical string.

For compliance, see 6.6.3.8.2.

5.3.6.3.4.3 *Torque* pulsations and torsion considerations

Torque pulsations are electromagnetically produced as a result of voltage and current harmonics in a *converter* fed *motor*.

Disturbing or dangerous influences on mechanical structure elements, such as excitation of torsion resonances of the *motor* and driven equipment, should be avoided during normal operation and under fault conditions.

Necessary analyses and corrective actions should be defined and managed by the *system integrator* and should be undertaken in close cooperation between *converter*, *motor* and driven equipment experts during the PDS and extended product design process.

For safety, apply IEC 61800-5-1, IEC 60034 (all parts), and other specific standards relating to the driven equipment as required.

5.3.6.3.5 Voltage stress of the *motor* winding insulation system

5.3.6.3.5.1 General

The *system integrator* should ensure that, in all practical conditions of operation, the voltage stress level does not exceed the insulation system voltage stress capability. Therefore, the *system integrator* is responsible for specifying the voltage stress level at the *motor* terminals, taking into account possible voltage reflection depending on the topology of the *converter*, cable type and length, etc. Relevant parameters for insulation stress are transient peak voltage values, peak rise time, repetition rate, etc.

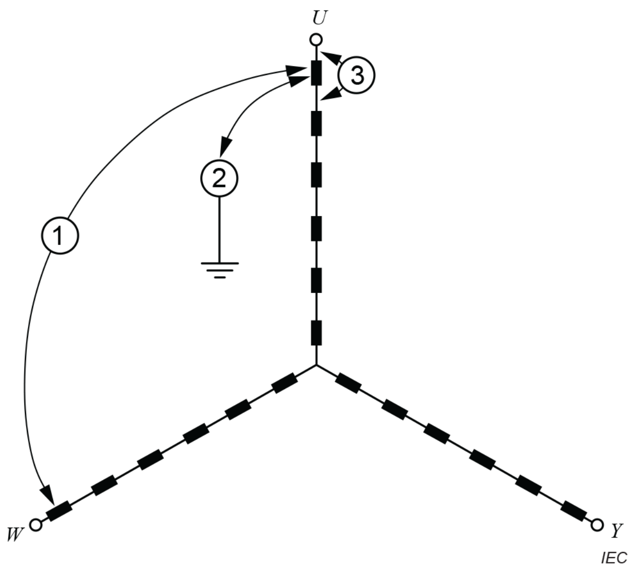
The *system integrator* should ensure that the *motor* selected will withstand the voltage stress of the application. To ensure that no service lifetime reduction of the *motor* insulation occurs, the actual stress due to *converter* operation should be lower than the repetitive voltage stress withstand capability of the motor winding insulation system.

For detail, see IEC 60034-25 and IEC TS 61800-8.

For testing options, see 6.6.3.8.5.

5.3.6.3.5.2 Types of winding stresses and limiting figures

Three different insulation stresses exist (see Figure 12).



Key

1 main insulation line to line

2 main insulation line to frame

3 inter-turn insulation in first coil

Figure 12 – Insulation stressing types

In line fed *motor*s (sinusoidal, low frequency), the most occurs in the line to line and line to frame insulation. The electric stress of the inter-turn insulation is relatively low; however, in the case of *converter* fed *motor*s, it can become very important and increased attention is necessary.

In a *converter* fed operation, the *motor* voltage is non-sinusoidal, typically with repeated transient voltage steps caused, for example, by fast switching PWM-inverters with relatively high pulse frequencies or by load side commutation notches of a thyristor *inverter*. In case of PWM voltage source *inverter* with motors fed via relatively long cables, each transient voltage step leads to reflections at the *motor* and the *converter* terminals with typically oscillating voltage overshoots (Figure 13).

t_a is the peak rise time of the voltage step (including the mentioned reflection phenomena). Definition of t_a is given in IEC 60034-25 as the time for the voltage to change from 10 % to 90 % of the total transient voltage Δu including overshoot (see Figure 13).

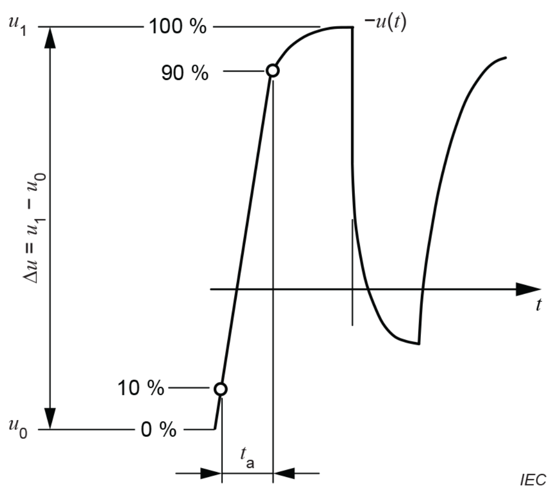
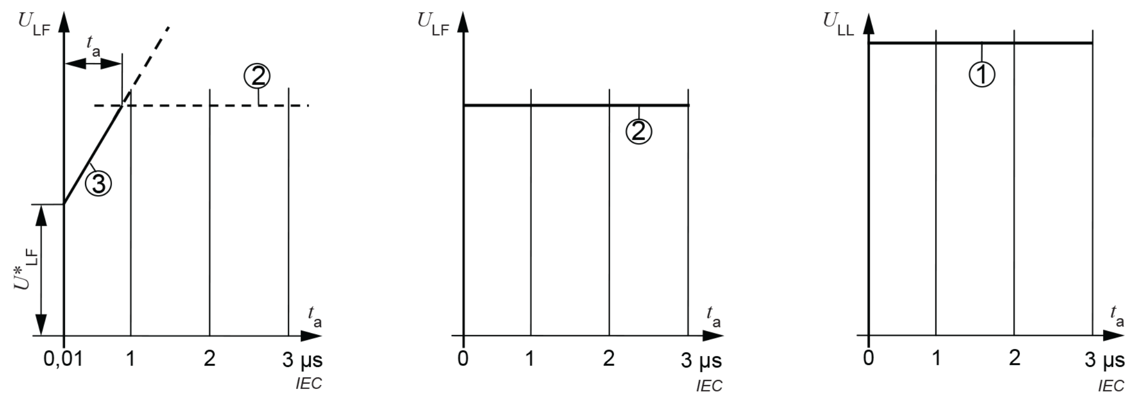


Figure 13 – Definition of the transient voltage at the terminals of the *motor*

The repetitive voltage stress withstand capability of the winding insulation system without service lifetime reduction can be described by the border lines given in Figure 14 a), Figure 14 b), and Figure 14 c). These borderlines refer to the admissible pulse voltage, including voltage reflections at the *motor* terminals. The numbers (circled 1, 2, 3 not on x-axis) in Figure 14 are common references to Figure 12 and to Table 9.



a) Determined by interturn insulation and winding design

b) Determined by main insulation line to frame

c) Determined by main insulation line to line

Figure 14 – Admissible pulse voltage (including voltage reflection and damping) at the *motor* terminals as a function of the peak rise time t_a

Figure 14 represents:

– inter-turn stressing type 3 relevant for transient voltage steps ΔU_{LF} with typical peak rise time $t_a \leq 1$ µs (Figure 14 a));

– voltage differences up to the withstand capability of the main insulation according to Figure 14 b) for line to frame stressing type 2;

–voltage differences up to the withstand capability of the main insulation according to Figure 14 c) for line to line stressing type 1.

5.3.6.3.5.3 Typical voltage stresses capability of *motor*s with usual design

Deriving from the insulation stress at line operation with usual voltage tolerances, the usual design of *motor*s gives at least a withstand capability indicated in the right column of Table 9. These formulae are given for guidance, if no further information is available from the *motor manufacturer* and represent minimum values. Significant higher voltage limitations are often proposed.

Table 9 – Limiting parts and typical voltage stress capability of the *motor* insulation system

Limiting part of insulation system	Relevant peak voltage value	Voltage stress capability of 3-phase motors
Main insulation, line to line, see 1 from Figure 14	U_{LL} line to line voltage difference	$U_{LL} = 1{,}1\ U_{Ins}\sqrt{2} \approx 1{,}6\ U_{Ins}$
Main insulation, line to frame, see 2 from Figure 14	U_{LF} line to frame max. voltage difference	$U_{LF} = 1{,}1\ U_{Ins}\ \sqrt{2/3} \approx 0{,}9\ U_{Ins}$
Inter-turn insulation of first coil, see 3 from Figure 14	$\Delta\ U_{LF}$ voltage step t_a associated peak rise time (see Figure 13)	ΔU_{LF} at least 3 kV $t_a \approx 1$ µs See Figure 14 a)
U_{Ins} is the rated RMS voltage value of *motor* insulation system.		

NOTE 1 The "rated voltage of insulation system" U_{Ins} (shown in Table 9) is not necessarily equal to the "rated *motor* voltage" U_{AN}.

NOTE 2 In the case of *inverter* fed *motor*s, it is often appropriate to use a *motor* design with improved insulation systems having $U_{Ins} > U_{AN}$ (*motor*) .

NOTE 3 As Figure 14 a) shows, the inter-turn insulation of the first coil is the limiting part for permissible transient voltage steps ΔU_{LF} in case of relatively short peak rise times in the range 0,01 µs ≤ t_a ≤ 1 µs.

For $t_a > 1$ µs, the relevant limitations are normally given by the main insulation (Figure 14 b) and Figure 14 c)).

NOTE 4 Because the switching of semiconductor elements in each phase occur at different times, the line to line voltage and the line to frame voltage have corresponding transient voltage steps $\Delta U_{LL} = \Delta U_{LF}$.

5.3.6.3.5.4 Functional evaluation of motor winding insulation systems

Test procedures for winding insulation systems used in *motor*s of rated voltage above 1 000 V should be in accordance with IEC 60034-18-31. Special attention is required, because of the additional stress factors produced by the *converter* fed operation such as increased voltage stress and high frequency repetition rate, additional heating as a result of harmonic losses and mechanical vibrations.

5.3.6.3.6 Designation of essential data

The following information may be of interest in addition to the normal rating plate of the motor:

– *rated torque*;
– *torque* at *minimum speed*;
– lowest *speed* at *rated torque*;
– *minimum speed*;
– base *speed*;
– maximum *speed*.

The following additional information may be necessary for a proper system design and installation of the motor, and may be supplied separately, for example in the product documentation:

– rotor moment of inertia and, if required, *motor* shaft stiffness for torsion investigations;
– additional *insulation* system data such as rated voltage;
– direction of rotation, and limit if any;
– air flow and surrounding requirements for *motor* cooling system;
– *motor* impedances (if required);
– relevant mounting dimensions;
– the shaft, the dimensions and the balancing should be in accordance with ISO/IEC, unless otherwise specified, "half key balancing" is relevant;
– mass of *motor* (rotor, stator);
– instructions for transportation, handling and storage;
– safety and maintenance instructions.

For detail, see IEC 60034 (all parts).

5.3.6.3.7 Bearing current

See IEC TS 61800-8 for detail.

For compliance, see 6.6.3.8.4.

5.4 Performance

5.4.1 Operational

5.4.1.1 General

The ratings of included features of the *BDM/CDM/PDS* should be specified by the appropriate *manufacturer*. One or more of the following features can be included (this list is not intended to be exhaustive):

- timed acceleration/deceleration;
- *dynamic braking*;
- reversing;
- *regeneration*;
- line filtering;
- input/output data processing (analog/digital);
- automatic restart;

- *DC braking*.

5.4.1.2 Steady state performance

5.4.1.2.1 General

The control system is in a steady state when the reference and operating variables have been constant for more than three times the settling time of the control system and the service variables have been constant for more than three times the longest time constant of the equipment (for example, the thermal time constant of the *speed* sensor). Steady state performance for drive variables such as *torque*, *speed*, position etc. should be considered in accordance with 5.4.1.2.2 to 5.4.1.2.5.

For compliance, see 6.6.3.9.

5.4.1.2.2 Deviation band

The deviation band (see Figure 15) is the total excursion of the directly controlled variable (unless another variable is specified) under steady state conditions as a result of changes in the service or operating conditions within their specified ranges.

The deviation band is expressed:

- as a percentage of the ideal maximum value of the directly controlled (or other specified) variable (see example in 5.4.1.2.3);
- as an absolute number for variables which have no readily definable base, such as position.

The signal representing the directly controlled variable should be filtered, for example by a first order low-pass filter with a 100 ms time constant, in order to remove noise and ripple from the signal.

NOTE The deviation band cannot be used to specify items which are not related with the steady state control performance (e.g. *torque* pulsation, or the *speed* ripple caused by load *torque* or *motor torque* pulsation).

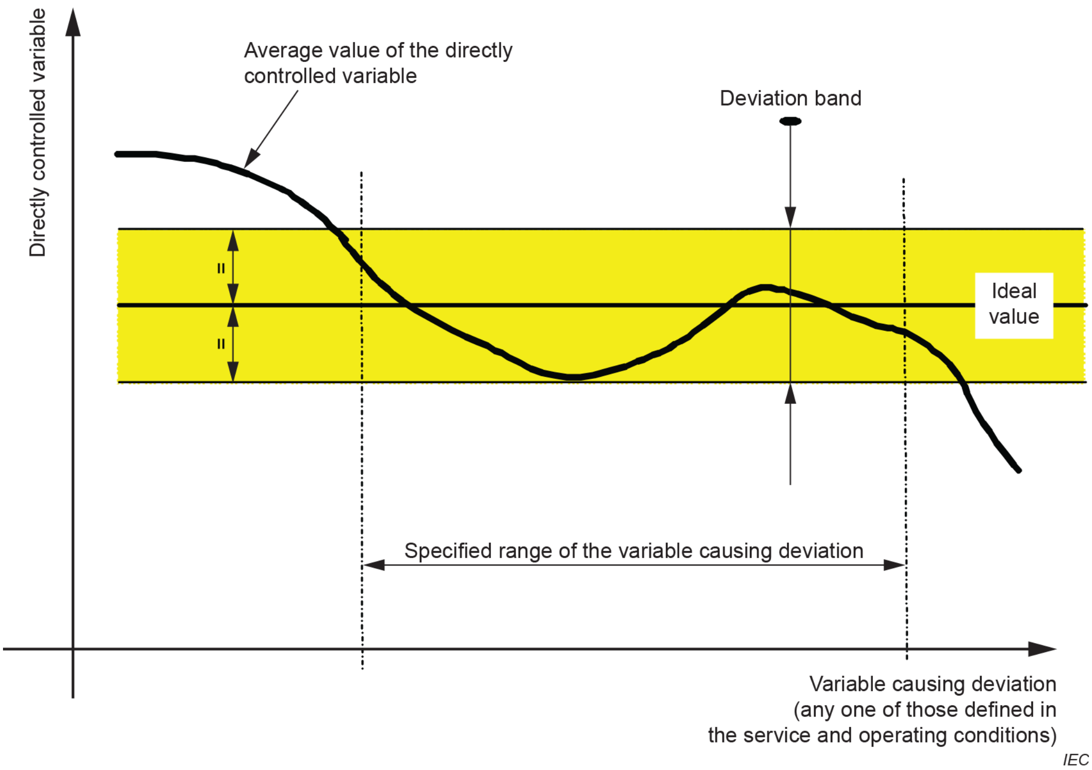


Figure 15 – Deviation band

5.4.1.2.3 Selection of deviation band

The steady state performance of a feedback control system can be described by a number, selected from Table 10, or a different level can be selected if appropriate for the application.

The range of variables to which the deviation band applies can be specified (see Figure 15).

Table 10 – Maximum deviation bands (percent)

±20	±10	±5	±2	±1	±0,5	±0,2	±0,1	±0,05	±0,02	±0,01

EXAMPLE A *PDS* has a 60 Hz; at 1 780 r/min *motor* that is fed by a frequency *converter*. The maximum *speed* of the *PDS* is 2 000 r/min and the specified deviation band for the speed control is ±0,5 %. Operating conditions are: *speed* range: 0 to 2 000 r/min; load *torque* range: zero to *rated torque*. Service conditions, ambient temperature range: 5 °C to 40 °C.

Thus, the deviation of the actual *speed* from the ideal value (speed reference) is:

±0,5 % of 2 000 r/min = ±10 r/min

when the value of the *speed* reference, load *torque* and ambient temperature are within their specified ranges.

For example, if the *speed* reference is 1 200 r/min, the actual *speed* of the *motor* will be 1 200 r/min ± 10 r/min, that is between 1 190 r/min and 1 210 r/min.

5.4.1.2.4 Service deviation band – Limits

The service deviation band specified by *BDM/CDM/PDS manufacturer*(s) should be followed under any combination of applicable service conditions at any time during any 1 h interval following a warm-up period, with the operating variables held constant during the observation.

5.4.1.2.5 Operating deviation band – Limits

The operating deviation band of the directly controlled variable should not be exceeded for the range of the operating variable indicated. The service conditions shall be held constant during the observation.

When required by the application, the performance information should also include data on the steady state relationship of the directly controlled variable to the reference. This aspect of performance is not included in the above discussion of operating or service deviation bands.

5.4.1.3 Dynamic performance

5.4.1.3.1 General

The dynamic performance of the *BDM/CDM/PDS* varies greatly based on application. There are many ways in which dynamic performance is achieved, including: current-limit, timed acceleration, inertia limits, ratio of voltage and frequency (V/Hz), etc. These parameters should be considered with respect to the final design of *PDS* and extended product with focus on the application need. For compliance, see 6.6.3.10.2, 6.6.3.10.3, 6.6.3.10.4, 6.6.3.10.5.

5.4.1.3.2 Time responses

5.4.1.3.2.1 General

Time response represents the output versus time curve resulting from the application of a specified input, under specified operating and service conditions.

The *PDS* should operate before the application of a specified input under the following operating and service conditions: