IEEE STANDARD 1566-2015 PERFORMANCE OF ADJUSTABLE SPEED AC DRIVES RATED 375 KW AND LARGER

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Abstract – This paper presents the main revisions, updates, and additional materials that were added to the IEEE 1566 Adjustable Speed Drive standard first published in 2005. The revised standard addresses suggestions and additions received from end users, manufacturers, and consultants over the last 10 years and will reflect both field experience and advancements made. The paper also addresses the comprehensively revised and expanded data sheets available for completion by the purchaser and manufacturer. The data sheet is available in Excel format for ease of completion. A new section entitled "Technical Data Sheet Guide" explains the various terminologies used in the standard to help the user. Recommendations are made for future work.

Index Terms — Adjustable Speed Drive, Definition, Standard, Performance, Data Sheet, Power Quality.

I. INTRODUCTION

One of the principle activities of the Institute of Electrical and Electronic Engineers (IEEE) is the creation of standards. The institute's mission statement is that "IEEE's core purpose is to foster technological innovation and excellence for the benefit of humanity" [1]. Their vision is for the IEEE to be essential to the global technical community and to technical professionals everywhere, and that it be universally recognized for the contributions of technology and of technical professionals in improving global conditions [1]. Therefore, it is logical for standards to be one of the primary means for IEEE to achieve this goal and that one of the organizations within IEEE is the Standards Association (IEEE-SA). The standards organization is responsible for developing global standards for many industries including: power and energy, biomedical and health care, information technology and robotics, telecommunication and home automation, transportation, nanotechnology, information assurance, as well as oil & gas, and many more.

A. Process Overview

The standard development process has been well defined and documented and is available to all members on the IEEE Standard website. Every effort is made, as part of the process, to ensure that input to the standard is contributed from a balanced representation of those who will be utilizing it or directed by it and that all input is recognized and addressed.

Fig. 1 depicts the overall standard generation process. Once a standard has been published, it is required that the standard either be revised or withdrawn after a set period of time to ensure that it remains current. At the time that IEEE Std. 1566 was established in 2005 [2], that time period was 5 years. This has been recently changed to a 10 year period as shown in Fig. 1.

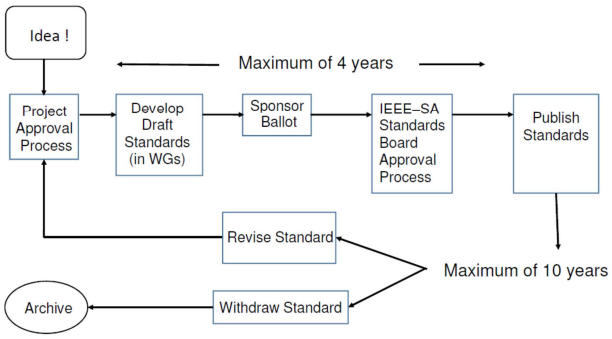

Fig. 1 IEEE Standard Development Process

B. Synopsis of the 1566 Standard

The IEEE Std. 1566-2015 standard [3] applies to AC adjustable speed drive (ASD) systems rated above 375 kW (500HP) and above 750V output voltage as used in petrochemical and similar applications. These systems are also referred to as variable frequency drive (VFD) systems, variable speed drive (VSD) systems, and power drive systems (PDS). The standard covers the performance requirements for an ASD system including, but not limited to, input switching device, input impedance (transformer or reactor), power electronics, control interfaces, cooling system and motor. A generic block diagram of an ASD system showing the elements which could apply is given in Fig. 2 [3].

Requirements for power quality, engineering analysis, start-up assistance, training, and spare parts are also covered in the standard. It is important to note that the

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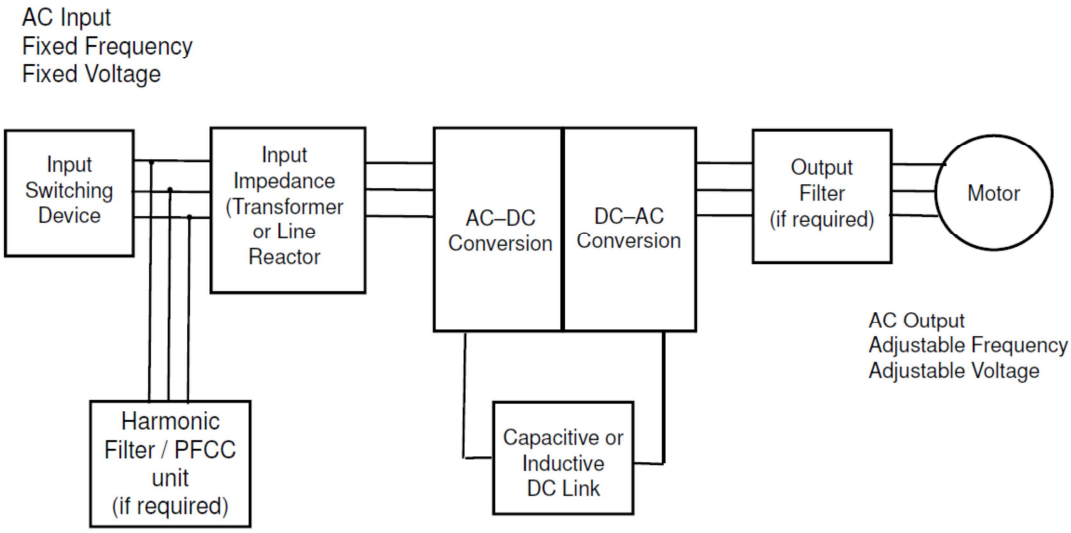

Fig. 2 Generic block diagram of an ASD system

intent of the standard is to define and specify the performance of the ASD system rather than to dictate the detail design of various components. In the medium voltage drive category covered by the standard, there are a number of topologies that are currently available, each with its own strengths and application considerations. Key to the standard are the data sheets which are associated with it as Annexes A and B. While the body of the standard provides guidelines which should be followed and met in the design and performance of a drive system, Annexes A & B contain technical data sheets which provide essential design criteria that must be completed by the appropriate parties and exchanged at the onset of the project as well as maintained throughout the project. For example, certain features as well as scope items such as the motor, switchgear, or transformer may be required or excluded from the scope of vendor supply if specified in the data sheets. The responsibility for completing Annex A lies with the purchaser of the equipment as it is essentially a list of requirements. Completion of Annex B is the responsibility of the equipment manufacturer in response to Annex A, and contains information relating to the application and to the selected ASD.

An additional objective of the working group in this revision was to change the format of the datasheets from a "static" pdf version to something that was easier to work with electronically. For this reason, the datasheets are now available in an Excel format as well as pdf.

What was originally Annex C has been changed to Annex D. Annex C is now a technical data sheet guide which gives further insight into the items and requirements on the Annexes A and B datasheets such as the basis for the required information and an explanation of each item.

Annexes D, E, and F are informative sections of the standard providing guidance on engineering studies, specialized applications, and the reference bibliography for the standard respectively.

C. Information on the Working Group (WG)

The IEEE Standards Association is not a government affiliated entity but rather a community. The standard development process which has been established by the IEEE-SA is intended to ensure balance, openness, fair procedures, and consensus.

The IEEE 1566 working group is one of the larger groups in the standards association. It is made up of volunteers from various backgrounds and roles ranging from manufacturers to end users whose purpose is to contribute to their profession through the generation of standards documents for the benefit of all. Balanced participation is mandated by the IEEE standards approval process which requires that there is representation by consensus with checks and balances in the process to ensure this is maintained.

Balance is important since the viewpoints which are expressed throughout the standard are without bias and often stretch goals fostering future development.

D. Intended users

IEEE Std. 1566 is intended for anyone working with ASDs but particularly for those in a role that requires the procurement of this type of equipment. While beneficial as a procedure to those with experience, it is particularly helpful to those who are less experienced since it provides an effective guide based on the accumulated knowledge, and experience of many other colleagues.

This is even more important when one considers the significantly increased usage of medium voltage drives in recent years.

Consider that the use of ASDs has steadily increased since their initial introduction in the 1970's. A number of manufacturers today produce more drives in one year in a

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single manufacturing facility than the entire demand recorded in the year 2000.

In addition to streamlining the order entry process, a further significant benefit of the standard to manufacturers is that the standard provides key target design information to manufacturers. It was recognized when the standard was first established that existing ASD designs would be unlikely to meet all requirements of the standard. Since that time, manufacturers have recognized the requirements and either enhanced their existing products or designed new equipment with the requirements given in IEEE Std. 1566 in mind.

E. Why a revision was needed

A revision of the standard was required as part of the IEEE process as described earlier in the paper. This requirement is to ensure that the standard remains current by addressing changes identified by the 1566 working group. Items requiring attention were:

- The introduction of new and revised drive related standards since the 2005 revision of IEEE1566 required the update and addition of new references to keep the standard current [4]
- New ASD technologies which have been introduced to the market since the completion of the standard
- Increased industry focus in the areas of arc flash and safety.
- Other enhancements identified by the working group during the use of the standard

During the course of the proposed revisions, new topics did arise which the working group has captured in order to consider them in the next revision of the standard.

II. MODIFICATIONS TO THE STANDARD – TECHNICAL CONTENT

The IEEE Std. 1566 [2] has been modified and updated to reflect growing knowledge and experience in the industrial application of ASDs. This increased knowledge and experience has enabled a restructuring of the standard that offers better and firmer guidelines. It is strengthened by cross references to other standards and by feedback from manufacturers and end users, appropriate inclusions, given that ASDs are now very widely used in many industries. This summary of updated modifications to IEEE Std. 1566 is intended as a summary only and as a guide to changes that should be read in full as detailed in the actual standard.

A. Application

The Application section of the standard includes modifications and additions in areas of minimum availability, mean time between failures (MTBF), and mean time to repair (MTTR)

Minimum availability is now defined as 99.8% over a five year run.

MTBF now states, “For the purposes of reliability predictions MTBF parameters shall be verified by analysis and supported by field experience.” Additionally, it is noted that for a drive to achieve five years of 99.8% availability, it should be designed to achieve a MTBF of not less than eight years.

With respect to MTTR, external events unrelated to ASD direct failure e.g. utility power supply failure or operator error, are not to be included in reliability and availability data. The expected performance of an ASD engineered to IEEE Std. 1566 [3] requires that a parts’ change should be completed within an hour and the system returned to operation at a 95% confidence level within three hours. These expected times do not apply when external constraints extend the time e.g. “isolation” and “return to operation”.

B. Normative References

In order that only up to date information is used, normative references in the standard no longer include issue dates. It is the responsibility of all users of the standard to search out the latest edition of the normative references. Note: In IEEE Std. 1566, P519 is now a fully issued standard and becomes IEEE Std. 519 [5].

IEEE Std. 1566 [3] contains two new power quality normative references: IEEE Std. 1250 [6] and IEEE Std. 1564 [7] relating to voltage sags.

C. Definitions, Acronyms, and Abbreviations

The section of the standard that includes definitions has been extended to include acronyms and abbreviations that are used throughout the standard. It is intended that readers familiarize themselves with the information and that it will help with reading of the standard.

D. Unit Construction

When specified, electronic boards shall have conformal coating applied. There is a requirement for the nameplate to include number of phases, nominal input current, and maximum short-circuit rating.

E. Adjustable Speed Operation

The Adjustable Speed Operation section of the standard relates to the core operation of an adjustable speed drive. A new section addresses ride through. Two sections represented in the previous publication of the standard, capacity and acoustic noise level, are extensively improved. Additionally, there are changes to the sections relating to power supply, transient overvoltages, voltage sags, loss of voltage, swells, voltage distortion, and harmonic distortion.

1) *Power Supply*: There is a clarification of responsibility in the provision of power. The responsibility for providing power to external output logic devices lies with the end user.

2) *Capacity*: The capacity of the system is considered in some detail in order to avoid system unreliability and satisfy economics. Both supply voltage tolerances and load requirements are addressed. It is widely accepted that the system operates on a continuous thermal safety margin of 10%. However, the standard acknowledges that, although a 10% safety margin is advisable, there are situations where, if the load is known not to require it, 10% may not need to be included. However, the magnitude and duration of the overload must be selected according to the specific

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application and take into account specific torque requirements (variable/constant). The overload must be appropriate for the application. The motor must be provided with sufficient breakdown torque with margin appropriate for the application. Once selected, the information is to be provided in Annex A.

3) *Transient Overvoltages*: Transient overvoltages from the electrical supply are addressed as potentially damaging. It is the end users' responsibility to provide transient protection for severe instances of overvoltage beyond those described in the standard e.g. lightning protection and surge suppression. See Fig. 4.

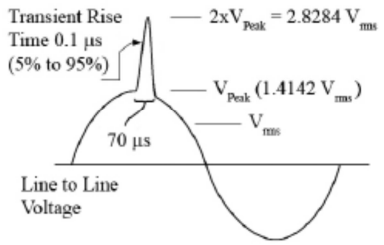

Fig. 4 Instantaneous voltage transient (not to scale)

4) *Voltage Sags*: Additional information about voltage sags has been added: "Unless otherwise specified, the drive system shall ride through and maintain control of the motor during an input power and/or control supply voltage sag down to 65% of nominal on one or more phases for a duration of 500ms." The implication is that a UPS should be considered for the control supply.

Additional information about voltage sags is available as set out in references [6] and [7].

5) *Supply Voltage Ride Through*: ASD supply voltage ride through is new to this publication of IEEE Std. 1566 [3]. "The intent of this requirement is to achieve safe and predictable operation during a power and/or control supply voltage sag or loss event (severe sag)." "The sag event could be: any phase-to-phase, any phase-to-ground, any phase-to-neutral, multiple phases, multiple phase-to-ground, or multiple phase-to-neutral." In essence it is necessary to understand and quantify all potential utility disturbances and make appropriate provisions in the ASD logic. The ride through section of the standard explores this subject and provides mitigating strategies. Fig. 5 provides an illustration of a sag event with useful terminology.

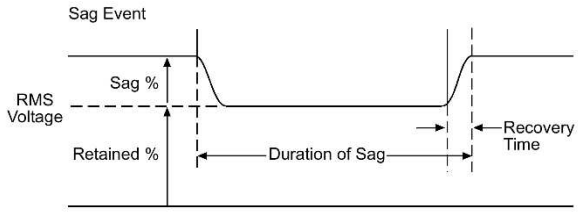

Fig. 5 Voltage Sag (not to scale)

6) *Loss of Voltage*: The drive system shall withstand a 100% loss of voltage in one or more phases of the input power supply for 2 s or longer without losing control capability. In this case, the drive shall cease output and, upon restoration of supply, shall have the capability to restart, catch, and reaccelerate the spinning motor to its original speed. When considering loss of voltage it is likely that an uninterruptible power supply (UPS) will be needed for the ASD auxiliary control power in a case of 100% loss of voltage.

7) *Three-Phase Voltage Swells*: The equipment shall operate continuously during a three-phase voltage swell to 115% of nominal for a period of 500 ms. The standard cautions, that in order to avoid drive component damage, an automatic restart should be avoided under swell conditions.

8) *Voltage Distortion*: The voltage distortion section includes a cautionary note that if voltage distortion occurs there may not be a compliance with IEEE Std. 519 [5] during the distortion event. Such distortion isn't covered by IEEE Std. 519 [5] as the distortion is likely to originate from a utility voltage event unconnected to the operation of the ASD.

It should be noted that the IEEE has issued an errata to correct the numbering duplication in the original printing.

9) *Voltage Unbalance*: The standard requires that the ASD operate at full rated output with 3% voltage unbalance. In order to give the ASD vendor some flexibility the following note has been added. "For some ASD topologies, meeting a voltage unbalance requirement as high as 3% may lead to additional cost. In those cases where the anticipated unbalance is expected to be significantly less, it may be advisable to stipulate this to the supplier to avoid unnecessary additional cost."

10) *Harmonic Distortion*: When considering harmonic distortion it is necessary to identify the specific location of the ASD in the electrical system (the point of common coupling, PCC) to predict harmonic distortion. This, in turn, will help in the correct application of IEEE Std. 519 [5]. In locations other than PCC an applicable standard may be IEC 61000-3-6[8]. The chosen standard must be identified in Annex A.

11) *Acoustic Noise*: The acoustic noise level section has been expanded to clarify the noise level measurement methods. Essentially, when measuring equipment noise any transformers or filters mounted in the same location as the drive should be included in the noise measurements. A minimum of four measurements should be taken and averaged. Cautionary notes warn that ambient noise in a test area or on site could interfere with correct assessments of noise levels.

F. Control

In the section dealing with control, the local and remote control sections have been reformatted with bullets for easier reading.

G. Input Transformer or Reactor

The minimum requirement for primary winding taps has been changed to "two (off-load operated) 5% taps: one above and one below nominal voltage."

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H. Motor

An additional requirement has been placed on the motor driven by the ASD "In the event the motor is to be installed in a classified area, refer to Annex D."

Additionally, a new warning has been added to the synchronous motor section. "A constant voltage power supply, such as a UPS, is often desirable to maintain voltage to the field during transient power occurrences."

I. Cooling System

1) *Air Cooling*: For the air cooling requirements, an additional recommendation has been made. "The fan motors shall have an L10 bearing life of 50,000 h per ANSI/ABMA 9 [9]."

An additional warning has been added related to air cooling. The air drawn into a drive must be carefully evaluated for chemical vapor hazards. Should vapors be present the air should be suitably filtered and circuit boards should be treated with conformal coating for protection. The presence of chemical vapor hazards should be stated in Annex A.

2) *Liquid Cooling*: For liquid cooling the range of temperature has been extended below -40°C. Should such a condition be expected to be encountered it must be stated in Annex A.

J. Engineering Studies

The addition of Annex C, Data Sheet Guide, has caused Engineering Studies to be renamed as Annex D and the Bibliography to be renamed as Annex F. A new Annex E has been created to address specialist applications that include classified areas, long cable distances, marine, and local generation and limited supply capacity

K. Inspection and Factory Tests

1) *High Potential (hipot) Test*s: Hipot tests are now required to be completed in accordance with UL 347 [10].

2) *Production Tests and Control*: An additional recommendation is made that, should the specified motor not be available, the ASD vendor is to supply a suitable substitute load. Such a load may not be sensitive to phase rotation and so additional care should be taken in evaluating the test results.

L. Shipping, Handling, and Storage Requirements

This new section deals with practical aspects of transportation and delivery. The purpose is to avoid pitfalls associated with transporting, handling, and storing equipment. This is a comprehensive summary and contains practical advice based on firsthand knowledge and experience.

M. Commissioning and Startup Assistance

In field testing there is a warning that hipot testing is a destructive test. Should such testing be required, a mutually agreed test level should be applied.

A statement, previously a note, has been elevated to become a direct requirement of the field testing. "When specified, the ability of the ASD to ride through temporary voltage disturbances shall be verified as part of the commissioning procedure. The vendor and the purchaser will jointly develop this method of verification."

N. *Data Interchange*

The Data Interchange section has been reformatted to improve readability.

O. Arc Flash

The importance of covering the dangers of arc flash events was recognized by the team and is included in Annex C. It is considered in conjunction with supply rating and grounding. Also in Annex C, the intention to expand further the section on arc flash in the next revision is noted.

III. DATA SHEETS

Considerable effort was spent by the working group to reformat the data sheets in order to capture key information, make it easy to complete, and to reflect, in chronological order, the requirements listed in the body of the standard. Also, the data sheets' layout was revised to be used as a standalone document and may be separated from the main body of the standard for ease of exchange of information between the purchaser and manufacturer. Annex A is to be used by the purchaser to complete the technical data information and Annex B is to be completed by the ASD manufacturer. Tables 1 and 2 show an extract of Annex A and Annex B, respectively. It should be noted that, for clarity, a section or subsection number may be shown beside the line item.

The data sheets presented in both Annex A and B of the standard represent a checklist for both the purchaser and manufacturer to complete. It is recommended that this information be provided at the early stage of a project and during a quotation and that it takes into account the number of requirements that must be addressed during the course of a project. It is most important to address these items up front and include them in the project planning budget in order to schedule effectively. It is intended that the use of data sheets will avoid the potential for scheduling delays and cost overruns.

Both Annex A (Technical data sheet to be completed by the purchaser) and Annex B (to be completed by the manufacturer) were thoroughly revised to reflect reviewers' feedback and changes made since the original standard was published in 2005. In addition, for ease of use, both annexes are now available from the IEEE Standards Association as Excel spreadsheets. A hyperlink is given for Annexes A and B for ease of navigation and download of the Excel format. The working group collaborated with IEEE standards' staff to achieve this and it is believed this is the first time that such a useful feature has been offered in an IEEE standard. Note that each sheet is a separate tab in the file and that both the sheets Annex A and Annex B are in this file. The link is: http://standards.ieee.org/downloads/1566-2015/.

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Annex A: To Be Completed By the Purchaser

For clarity, the numbering system of items discussed here are referenced to the actual sheet number, line number, and either left or right column in the standard. For example, A1 – 15L refers to sheet 1, line 15 and left column to be completed by the purchaser in the data sheet of Annex A. Letter R is for right column. The following are the key changes that have been made:

A1-15L Minimum and maximum three phase short fault level at drive input and respective clearing time for arc flash calculations.

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TABLE 1
EXTRACT OF DATA SHEET FROM ANNEX A TO BE COMPLETED BY THE PURCHASER

ANNEX A, SHEET 1 OF 3 — TO BE COMPLETED BY THE PURCHASER

System of Units: ◯ SI ◯ SI plus US standard

Supply System Voltage (6.1, 6.6):

◯ 2400V ◯ 3300V ◯ 4160V ◯ 6600V ◯ 6900V ◯ 13800V

Other: _____ V ±_____ %

3 ϕ Short-Circuit Level: _____ kA at PCC _____ at drive

Line Frequency: ◯ 60Hz ◯ 50Hz

3 ϕ Short-Circuit Level: _____ kA _____ at drive

Line Frequency: ◯ 60Hz ◯ 50Hz

3 ϕ Symmetrical Short-Circuit Level at Drive Input for Arc Flash Calculations:

_____ Maximum kA _____ Minimum kA Duration: _____ ms

ASD Auxiliary Three-Phase Power (6.1):

60Hz: ◯ 208V ◯ 480V ◯ 600V ◯ Other: _____ V

50Hz: ◯ 400V ◯ Other: _____ V

Control Power (7.1):

◯ From Input ◯ UPS ◯ Battery ◯ Voltage _____ V

Redundant Control Power Supplies: ◯ Yes ◯ No

UPS or Battery Supplied by: ◯ Vendor ◯ Purchaser

Harmonics (6.2, 6.16):

Impedance versus frequency data supplied at PCC? ◯ Yes ◯ No

Point of common coupling (PCC): _____ Voltage at PCC: _____ V

Required telephone influence (I.T) at PCC: _____

Average Demand Current (I_L): _____

Other harmonic requirements: _____

Harmonic Compliance to IEEE 519: ◯ Yes ◯ No

Harmonic Compliance to IEC 61000-3-6: ◯ Yes ◯ No

If 'No' to both of the above, state voltage THD requirement at PCC: _____

System Grounding (6.5):

System Ground method: ◯ Solid ◯ Resistance at: _____ A

◯ Other: _____

Ground fault detection provided in upstream switchgear: ◯ Yes ◯ No

Relevant National/Local Codes (4.1):

_____

Site Environment (1.3):

A1-22L The responsibility for providing auxiliary control power and UPS was clarified.

A1-27L An option was provided of choosing an ASD continuous rating as a percentage of motor full load rating at 100% or 110% or other. However, the magnitude and duration of overload capability must be selected according to the application.

A1-06R Harmonic compliance is expanded to include the point of common coupling, average demand current, compliance to IEEE 519 or IEC 61000-3-6 or as noted by the end user.

A1-16R System grounding covering solid, resistance or other.

A1-25R The site environment section is expanded to cover any potential contamination and for the electronic circuit boards to have conformal coating.

A2-22L Noise level as measured in the factory taking the entire ASD assembly.

A2-28R Isolating transformer and motor protection.

A2-33R Isolating transformer tap at ±5% or other.

A3-36L Factory acceptance testing was expanded to include the option of drive only testing or drive/motor testing or drive/motor/load testing.

A3-3R A new section was added regarding shipping, storage, and handling.

Annex B: To Be Completed By the Manufacturer

For clarity, the numbering system of items discussed here are referenced to the actual sheet number, line number, and either left or right column in the standard. For example, B1 – 11L refers to sheet 1, line 11 and left column to be completed by the manufacturer in the data sheet of Annex B. The following are the key changes that have been made:

B1-11L The vendor is expected to provide values of arc flash incident energy in cal/cm^2 at ASD input, power electronic cabinet and drive output cabinet based on data provided by the end user.

B1-21L The ASD auxiliary power requirements for various components including control power, cooling fans and pumps.

B1-30L The ASD continuous capacity and overload capability for 1 minute.

B1-37L The ASD ride through capability.

B1-41L The ASD MTBF and MTTR and if suitable for minimum five years of continuous operation.

B1-32R The DC link inductor and capacitor replacement frequency.

B2-15L Harmonic compliance to IEEE 519 or IEC 61000 and values of voltage and current THD at PCC.

B2-3R Isolating transformer or line reactor used. Winding material and if air or liquid cooled.

B2-30R The ASD vendor to state if motor derating is required, peak voltage at the motor and maximum allowable cable distance between the ASD and the motor.

B3-3L External ASD cooling requirements.

B3-20L Overall ASD efficiency and power factor at preselected speed and load.

B3-3R ASD current harmonic spectrum up to 49th order.

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TABLE 2
EXTRACT OF DATA SHEET FROM ANNEX B TO BE COMPLETED BY THE MANUFACTURER

ANNEX B, SHEET 1 OF 3 — TO BE COMPLETED BY THE MANUFACTURER

General Information

Vendor:_____ Manufacturing Location:_____

Model Number_____

ASD rating (5.3):

kW:_____ Input Voltage:_____ V Output Voltage:_____ V

Arc flash incident energy based on maximum and minimum kA fault level provided at Annex A (see Annex A for further guidance):

Drive input cabinet:_____ cal/cm^2

Power electronic cabinet:_____ cal/cm^2

Drive Output Cabinet_____ cal/cm^2

Supply system voltage (6.1):

☐ 2400 V ☐ 3300 V ☐ 4160 V ☐ 6600 V ☐ 6900 V ☐ 13800 V

Other:_____ V ±_____ %

Line Frequency: ☐ 60 Hz ☐ 50 Hz

Enclosure (4.2.1):

☐ Indoor, IP21 ☐ Other, Specify:_____

Gland Plate Location:

Incoming Power Cables: ☐ Top ☐ Bottom

Size_____ Number per Phase:_____

Motor Cables: ☐ Top ☐ Bottom

Size_____ Number per Phase:_____

Control Cables: ☐ Top ☐ Bottom

Finish: ☐ Manufacturing Std. ☐ As Specified

☐ Outside Colour: _____

☐ Inside Colour: _____

Rear access required: ☐ Yes ☐ No

Drive weight:_____ kg

Drive dimensions (W × D × H_____ mm

Rectifier (5.4):

Pulse number: ☐ 6 ☐ 12 ☐ 18 ☐ 24 ☐ 36

B3-11R Instructions for lifting, handing, and reassembly of the ASD on site.
B3-18R Recommended spare part lists.
B3-21R Commission and startup assistance.

IV. TECHNICAL DATA SHEET GUIDE

Some users of the original standard (1566-2005) [2] had commented that the Data Sheets were difficult to complete, and vendors reported problems with the data sheets they received. To address this situation the team produced a Data Sheet Guide (DSG) as Annex C of the Standard. The "Engineering Studies" Annex was moved from Annex C to Annex D so that the DSG could follow the Data Sheets. The guide has suggestions that advise the Purchaser in each section of the Purchaser Data Sheet. Note that the DSG is a guide only and does not necessarily address all applications that may arise.

The DSG starts with a general outline that lists all the components covered by the standard. It then follows in line with the order of the Purchaser Data Sheet itself and has suggestions for each point in the Data Sheet where a decision is required.

Some of the areas covered by the DSG are:

1) *General:* In the introductory section, a system block diagram is included. It shows all the components such as Input Switchgear, Harmonic Filters, Input Transformer/Impedance, Rectifier, DC Link, Inverter, Output Filter, and the Motor. Not all the listed components are required for each application, owing to the ASD topology. Also, the purchaser may decide to use items such as switchgear or motor that are not included in the particular order.

2) *Single Line Diagram:* The supplier of the drive system needs to know how the single line diagram relates to the overall power system. It must be understood also how it will enhance plant operations and what actions may have to be taken to meet the necessary requirements of the application.

3) *Power System Data:* The voltage at the drive input affects the transformer design and that at the PCC determines allowable harmonics per IEEE 519; the Short Circuit Level affects the allowable harmonics that can be exported to the external power system. In addition the range of available short circuit levels are required when calculating arc fault levels.

4) *Auxiliary and Control Power:* ASDs need control power for operation, and this can be derived from external sources such as an MCC, a UPS, a battery, from the ASD itself, or may be from redundant sources. There are a range of AC and DC voltages that are possible. The Vendor must know what is required to be able to make an accurate offer. The 3 phase auxiliary power is used mostly for cooling fans and pumps and is usually the voltage and frequency used for low power applications on site. Redundant supplies are often used, and, if so, this should also be specified.

5) *Continuous Rating:* Typically users like to have the power electronics rated for 110% of the motor current. However some users prefer to save money by using a 100% rated drive. If process requirements increase this can cause capacity limitations at some point. If the 100% capacity is specified, we recommend a detailed analysis of the requirements.

6) *Type of Load/Application:* Centrifugal loads such as fans, centrifugal compressors and pumps tend to have a torque requirement that varies roughly in proportion to the speed squared, while loads such as reciprocating

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compressors and conveyors tend to have torque requirements which are essentially independent of speed. These differences, plus load inertia, affect the design of the ASD, and should be provided to the Vendor.

7) *Power System Harmonics:* Although IEEE 519 is most commonly used as a standard harmonics requirement, some utilities have other requirements, and isolated systems may have more stringent requirements. In addition, although IEEE 519 calls for the PCC to be the connection to the utility, internal plant requirements may require harmonic limits at a system location closer to the ASD itself.

8) *Environment and Enclosure:* The ambient temperature both indoors and outdoors along with pollution, dust and humidity affect the heat transfer capabilities of the ASD and thus the internal temperatures of the semiconductors. In addition, the thinner air at higher altitudes reduces both the heat transfer and voltage withstand abilities of the air. Any issues here must be known by the vendor. In many cases, especially those where site labor is expensive, it is often more practical to install the ASD and associated equipment in a prefabricated building at a fabrication yard and transport the whole building and drive to site. Most vendors can supply these prepackaged systems if they are requested.

9) *Cabling:* Input and output power cables may enter the ASD from either top or bottom, and although most suppliers can accommodate either, they do need to know which is required, as well as their number, area, and voltage ratings. In some cases their inductances, capacitances, and lengths are required for drive performance reasons.

10) *Redundancy:* For increased reliability, redundant electronic system components may be specified so that failure of a single component will not cause a drive shutdown. Not all topologies can supply this redundancy, so a careful review of actual requirements is needed.

11) *Ride through and Flying Restart:* When there is a reduction in the supply voltage to the drive, the available torque also decreases and if the reduction is large enough the motor may not be able to drive the load Also the drive's auxiliaries, such as fans and pumps, may cease operating and the loss of control power may affect operation. The default requirement is for the drive to withstand a sag of supply volts to 65% of nominal for 0.5 seconds. Various options are available to address more extreme situations that should be specified. For example, a complete shutdown followed by an operator initiated restart when the supply is again "healthy", or a "Flying Restart", where the drive catches and reaccelerates the motor. For most restart situations battery or UPS supply of control volts is required.

12) *Communications:* Modern digital communications mean that an ASD can receive and supply almost unlimited quantities of information to the outside world, which helps in troubleshooting the associated process and the drive itself. The drive vendor should know what protocols and capabilities are required.

13) *Bypass Operation:* One common method of operation is to have a "Bypass" mode available where the motor can be supplied either at fixed frequency from the utility, or from the ASD with transfer between modes. This can improve system availability and also allows multiple motors to be started sequentially using one ASD. For example, some pipeline applications used 3 or 4 motors and one ASD with the ASD starting the first pump, then transferring it to the utility and starting another.

14) *Input Transformer/Reactor:* Most Medium Voltage ASDs use either an input isolating/phase shift transformer or a series reactor. The default is for the transformer/reactor to meet the relevant IEEE standards but other options are available. The ASD supplier should be told what is required.

15) *Motor:* There are some motor requirements such as critical speed locations, voltage withstand, and torque/speed requirements that are unique to motors operating on an ASD. The API motor specifications have clauses which discuss these requirements and these documents are recommended, but sometimes in retrofit situations an existing motor may be used. The supplier needs to know whether the motor is induction or synchronous, and be informed of all the other requirements such as speed range and torque requirements.

16) *Cooling:* The solid state devices, bus work, transformers, and reactive components are all subject to deterioration from excessive temperatures, and the solid state devices are usually the most sensitive. On lower power systems, air cooling is usually practical but on higher power systems direct liquid cooling is needed. Redundant fans and pumps are recommended.

17) *Testing:* It is desirable to do as much testing as practical in the ASD vendor's plant, to minimize startup issues. This extends to operating the whole system including input transformer, drive, and motor as a package, which can be expensive but if it is practical such action can shorten site time.

18) *Shipping, Storage, Handling:* Shipping from the plant, on site storage, and handling issues should be worked out between the supplier of the drive system and the eventual owner.

19) *Services:* The ASD vendor can provide engineering services during the manufacturing, application, and analysis phases of the project, and will probably be needed for startup on site. This should be defined clearly.

V. SPECIALIZED APPLICATIONS

As mentioned earlier in the paper, Annex E has been added to the standard. This portion of the standard provides additional application insight and guidelines which will be helpful for the system designer. These applications include:

1. Hazardous locations - either the motor or drive,
2. Long cable runs,
3. Marine applications
4. Operating off local generation

For particular situations such as these, more information needs to be shared with the ASD supplier so that the design can be optimized. Annex E is an informative annex and discusses each specialized application. It includes listings of the extra information that the vendor requires for each application.

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VI. FUTURE

The team is looking at the next edition of the standard and intends to address additional topics that are either not yet covered or need to be expanded upon such as:

1. Arc flash mitigation and withstand capabilities.

The 2015 document started in this direction with the addition of short circuit levels and durations being required of the Purchaser in Annex A. The next revision will expand on this with more requirements listed.

2. Drive protection zones

The protective elements will be defined which should be covered in the scope of drive protection.

3. Additional information

IEEE Draft Std. P1662 "Recommended Practice for the Design and Application of Power Electronics in Electrical Power Systems" [11] has many useful sections which can assist in further improving the standard in the next revision.

We encourage interested people from both the user and vendor areas to become involved in the next revision cycle so that the standard will have the benefit of as wide an experience base as possible.

VII. CONCLUSION

IEEE Std. 1566 has been updated in the second edition to reflect present day technology and now covers a number of areas which had not been fully addressed in the first edition. Users will find it an up to date reference document that can be used as a specification for Medium Voltage ASDs of all ranges and applications.

We strongly encourage purchasers to use the standard either as a standalone document or as the basis of a company specification. The data sheets to be completed by the purchaser and manufacturer are now available in Excel format for ease of completion and can be downloaded via a hyperlink provided in the standard. Filling in the data sheets is essential and merely mentioning IEEE 1566 without filling in the data sheets is not very useful.

VIII. ACKNOWLEDGEMENTS

The authors gratefully acknowledge the efforts of the team who spent many hours working to write and edit the standard. Those who contributed to the completion of the latest release of the standard including the IEEE staff are recognized on sheets vi and vii of the current standard. [3]

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X. VITAE

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