



RP 12-12

**ELECTRICAL SYSTEMS AND
INSTALLATIONS -
ELECTRICAL VARIABLE SPEED
DRIVES**

July 1994

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SCOPE AND PURPOSE This document details the recommended design approach for the application of Variable Speed Drive units within the types of industrial power systems operated by BP. It forms part of the RP 12 series of documents and supplements the basic design requirements outlined in BP Group RP 12-3.											
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FOREWORD

Introduction to BP Group Recommended Practices and Specifications for Engineering

The Introductory Volume contains a series of documents that provide an introduction to the BP Group Recommended Practices and Specifications for Engineering (RPSEs). In particular, the 'General Foreword' sets out the philosophy of the RPSEs. Other documents in the Introductory Volume provide general guidance on using the RPSEs and background information to Engineering Standards in BP. There are also recommendations for specific definitions and requirements.

Value of this Recommended Practice

This document represents the accumulated practices of the BP Group Companies for ensuring a high standard of plant integrity within the constraints for cost effective engineering.

Application

Text in *italics* is Commentary. Commentary provides background information which supports the requirements of the Recommended Practice, and may discuss alternative options.

This document may refer to certain local, national or international regulations but the responsibility to ensure compliance with legislation and any other statutory requirements lies with the user. The user should adapt or supplement this document to ensure compliance for the specific application.

Principal Changes from Previous Edition

This Recommended Practice is a major revision of BP CP 17 Part 12 Electric Variable Speed Drives which was last issued in November 1987.

Feedback and Further Information

Users are invited to feed back any comments and to detail experiences in the application of BP RPSE's, to assist in the process of their continuous improvement.

For feedback and further information, please contact Standards Group, BP International or the Custodian. See Quarterly Status List for contacts.



1. SCOPE

This Part of the BP Group RP 12 series specifies recommendations for the selection and application of electric variable speed drives. It does not include single phase a.c. motor variable speed drive applications or electric variable speed couplings.

This Recommended Practice is based upon the use of the following types of electrical variable speed drives:-

- | | | |
|-----|---|----------------------|
| (a) | Pole changing and 'Pole Amplitude Modulation' (PAM) |) |
| (b) | D.C. |) See section |
| (c) | Kramer |) 3.2.1 (commentary) |
| (d) | Variable frequency converter |) for more details. |

For application of variable speed drives other than these, this code may be used for general guidance.

2. GENERAL

2.1 Use of this Recommended Practice

This document is focused on variable speed drive application. The general requirements for power system design given in BP Group [RP 12-3](#) should form the foundation of all power systems design.

Where employed, variable speed drives will form part of a larger electrical installation. BP Group [RP 12-3](#) details the basic design approach, giving indication of power system analysis in support of design, which should be followed in undertaking the overall power systems design. This document, BP Group RP 12-12, provides information supplemental to the basic design document which is specifically directed towards the application of variable speed drives.

Variable frequency converters provide an inherent soft start feature for a.c. motors which can be beneficial in reducing the overall fault level required in the power system design. The voltage reduction of the power system during motor starting is also reduced.

Reduced rating variable frequency converters may be used exclusively as a soft starting means for large motors where the power system cannot support the large voltage dips caused by conventional starting means. However in order to minimise VSD rating, the starting condition needs to be with the machine unloaded.

A soft starting system becomes more economic when more than one motor requires to be started. Such a system would normally comprise one soft start frequency converter that would run-up each motor in turn, the motor would be synchronised onto the main supply leaving the soft start system ready to start-up the next motor.

3. DRIVE APPLICATIONS

3.1 Economic Assessment

An economic case for the use of electric variable speed drives in preference to fixed speed drives should be prepared and recorded.



An availability of this document which details the reasoning for the selection of a VSD is considered good practice and ensures that a sound case for the application exists and is in an auditable form which can also be employed to test the worth of future applications.

Where there is no alternative to the application of a Variable Speed Drive, the assessment becomes one of selection among alternative methods of Variable Speed Drive (see 3.2). The terms of reference for the economic assessment of energy saving schemes using electric variable speed drives, such as the marginal cost of power and the extent of the pay-back period should be identified and receive specific Project approval. It is recommended that aspects such as maintenance costs, power system 'cleanup' (the assurance that the voltage waveform is not unduly affected) and reliability should be accounted in the analysis.

The initial capital cost of electric variable speed drives is greater than for fixed speed electric drives, it is necessary therefore, to assess the economics of each application against the alternatives available (fixed speed electric drives, variable speed couplings, steam Turbines, gas Turbines etc.). Similarly in a retrofit situation where the use of non-electric drives, such as steam turbines and gas turbines, is being reviewed against electric variable speed drives, the economics should be assessed again.

Electric variable speed drives may be used for energy saving in such applications as drives for fans, blowers, pumps and compressors etc. In all instances the marginal cost of power for a given location should be applied to the estimated energy saving and assessed against the capital and maintenance cost of the electric drive installation. In some cases the capital cost associated with control valves may be set off against the capital cost of the variable speed drive and associated equipment as no modulating control valve would be necessary where motor speed can achieve the desired effect. (Note however the requirements of 4.7.2 which would require alternative modulating control methods for the process.)

3.2 Drive Selection

3.2.1 Where the economic assessment indicates that an electric variable speed drive application should be employed, the generic type of drive (or types of possible VSD which can then form part of a competitive bid tender) should be identified as part of the justification. The selection of the type of VSD should include considerations of driven equipment characteristics, environment for the installation, reliability/servicing and safety.

The drive types available for consideration are:-

(a) Pole changing and 'Pole Amplitude Modulation' (PAM) Drives

These types of variable speed drives are applied to a.c. induction motors and they utilise the changing of pole configuration to alter the fundamental speed of the motor. They only permit discrete step changes in motor speed.

(b) Direct Current Drives

These types of variable speed drives utilise the characteristic of the d.c. motor where an alteration of applied voltage alters the speed of the motor. The speed alteration in modern systems is arranged to be stepless by the use of force-commutated, solid state power switching devices, such as thyristors, fed from an a.c. supply and controlling a bridge rectifier supply to the motor. Direct current drives can have a high torque output characteristic over their speed range which makes them suitable as drives for high torque applications e.g. extruders. The disadvantages of d.c. drives is the need for brush gear and commutator maintenance.

(c) Kramer Drives

These types of variable speed drives make use of the characteristic that by varying the resistance of the rotor of a wound rotor induction motor, a speed change can be achieved. Modern Kramer drives incorporate a solid state slip energy recovery system which comprises a bridge rectifier fed from the rotor, a d.c. link, and an inverter. The inverter, which incorporates solid state power switching devices feeds rotor energy back into the motor stator circuit and a stepless speed variation is achieved by controlling the energy flow through the inverter.

Kramer drives are not normally economic where a wide speed range is required and they have the disadvantage of the need for brush gear and slip ring maintenance. The use of inverters in recovering the slip energy must also be taken into account when driven equipment vibration is considered as rotor current harmonics can introduce torsional effects.

(d) Variable Frequency Converter Drives

These types of variable speed drives provide an efficient means of stepless speed variation of a.c. motors of the cage and synchronous type, by varying the frequency and voltage of supply to the motor stator. Modern variable frequency converters comprise an a.c./d.c. converter or bridge rectifier, a d.c. link and an inverter, each incorporating solid state power switching devices as required. The method of operation varies according to the application. Speed and torque can be controlled across a wide range which makes this type of drive suitable for almost all applications except for very low speed operation when torque pulsations can occur.

Extruder drives have traditionally been d.c. drives because of the high torque that is available over the d.c. motor speed range. Modern variable frequency converter systems have now made it possible for a.c. motors to be considered for this application. However, where low speed operation is required particular attention should be paid to the selection of motor and VSD as vibration can be a problem.

3.2.2

The variable speed control for equipment located in hazardous areas should be housed within a building or enclosure located outside the hazardous area. Where it is necessary to locate the VSD control equipment within a hazardous area, the enclosure shall be explosion

protected in a manner which meets the requirements of IEC 79-14. (Refer also to 3.3.2).

It would normally be expected that the Variable Speed Drive power electronic control equipment for a motor located in a hazardous area would be located in a safe environment. There may, however be specific applications which require that the power electronics should also be located in the hazardous area. Where this is the case special enclosure protection needs to be employed. It is expected that such special explosion protection could comprise an Ex'p' system of protection and it will therefore be necessary for a defined shutdown method to be included in the system design in order to meet the requirements of an Ex 'p' system.

The construction of the explosion protection shall be certified by a Nationally recognised authority. Refer to BP Group RP 12-2 for further detail on the requirements of electrical equipment in hazardous areas.

- 3.2.3 Any transient voltage spike generated by an inverter on the load side of the VSD shall be less than 205% measured peak to datum of the nominal RMS voltage.

This requirement is specific to the application of VSDs to electrical submersible pumps where past experience has indicated that voltage spikes could cause premature failure of cable, connector, penetrator and motor connections. The limitation to 205% voltage is based upon field operating experience with VSDs which can readily meet this limitation.

Electrical submersible pump motors may be operated on unearthed systems at a voltage which may be higher than their variable speed controller output voltage. Therefore it will probably be necessary to include a step-up transformer in the VSD output for these drives. Special VSD/transformer co-ordination is necessary to avoid overfluxing the transformer during frequency changes.

3.3 Electric Machines

- 3.3.1 Unless re powering of an existing electrical machine is considered the VSD, machine and driven equipment (pump or compressor) should be specified and purchased in such a manner that one vendor has overall responsibility for the satisfactory operation of the item of plant.

The factors which must be considered include:-

- (a) Vibration effects.
- (b) Hazardous area certification.
- (c) Power matching for maximum process conditions.
- (d) Motor starting.
- (e) Provision of sufficient data for an assessment to be made of the effect of the VSD on the larger power system.

Where re-powering of an existing motor is required, the VSD vendor should, at bid stage, be provided with the mechanical details of the driven equipment (e.g. Radii of gyration, Inertia, Shaft Stiffness, Dimensions, Weights etc.) and should be charged with offering a system suitable for the application. Without the VSD



vendor undertaking this analysis either BP or a third party will need to be assured that the VSD will not cause mechanical vibration problems for the driven equipment.

For new plant, under normal circumstances, induction motors would be expected to offer the most cost effective design for the motor. There are three main types of solid state variable frequency converters for a.c. induction motors:-

- (a) Voltage source.
- (b) Current source.
- (c) Pulse width modulated (PWM).

With the voltage source type the a.c./d.c. converter stage is voltage controlled and generates a voltage in the d.c. link which is adjusted according to the required motor speed. The inverter stage converts the d.c. voltage into an a.c. voltage at the required frequency and the output voltage waveform approximates to a square wave (often referred to as quasi-square wave). A variant of the voltage source type has a rectifier fed constant voltage d.c. link and an intermediate 'chopper' stage feeding a variable voltage d.c. link.

The current source type of VSD for induction motor duty is similar to the normal voltage fed type except that the a.c./d.c. converter stage is current controlled and the motor phase current from the inverter is equal to the d.c. link current. As induction machines do not produce strong back EMFs at low speed, a supplementary method of Load Commutation and excitation is required. (See below for current source VSDs for synchronous motor duty.)

With the basic PWM type of VSD, the d.c. link is not controlled and the output voltage and frequency are controlled at the inverter stage. The output voltage comprises a number of square wave pulses per half cycle and control of the mark-space ratio of the output voltage waveform produces a synthesised sinusoidal current waveform.

Synchronous motors, once rotating, produce a back electro motive force (EMF) which can be used to commutate the inverter stage of a variable frequency converter and this results in a much less complex form of control when compared to VSDs which have forced commutation circuits (e.g. PWM or Voltage source types). The voltage in the d.c. link is controlled at the a.c./d.c. converter stage and the inverter stage is switched on by trigger impulses and switched off by the motor back emf. The motor phase current therefore equates to the d.c. link current. VSDs used in conjunction with synchronous motors tend to be of the current source type. Synchronous motors in VSD applications tend to be in larger power ratings where the cost advantages of the simplicity of the VSD outweigh additional costs associated with the synchronous motor. Such a VSD generally may not be operated on open circuit.

3.3.2 Any machine located in a hazardous area and powered by a Variable Speed Drive should be certified for use within the hazardous area in accordance with the requirements of clause 2.2 of BP Group [RP 12-2](#).

A machine located in a hazardous area and supplied by a VSD, in addition to being certified for use in a hazardous area, should have additional verification that the machine will be suitable given the details of the VSD and the operational speed range. The verification may be by test or by calculation but should meet the



approval of a recognised certifying authority. This can be a particular problem when retrofitting a variable speed controller to an existing motor.

For Ex(N) Zone 2 applications, the BS 5000 Part 16 requirement is to test the actual motor temperature rises whilst being supplied with the selected inverter. This is a 'type' test only i.e. need only be carried out once in the factory for the particular inverter and motor design selected. Some inverter manufacturers are keen to build up their collection of type tested inverters/motors.

Where output harmonics could cause an unacceptable derating problem with an a.c. motor fed from a variable frequency converter, the inverter stage may be of the twelve pulse type and should feed the motor via a dual primary, single secondary transformer. One of the primary windings should be star connected and the other delta connected in order to reduce the output harmonics.

- 3.3.3 Where only one or two step changes of speed are required for a particular mechanical load, such as a fan or pump or other exponential torque/speed application, a pole changing (PAM) a.c. induction motor drive system may be used. If the speed change is required without stopping the drive, the mechanical effect of the step change in torque on shafts and couplings should be assessed to ensure that no damage will be sustained. Where stepless speed control is required a.c. motors fed from variable frequency converters should be used.

It is considered that PAM motors would be a lower cost alternative than single speed machines in conjunction with other forms of VSD equipment.

- 3.3.4 Where a.c. electric drives are required to operate above their nominal synchronous speed, variable frequency drives in conjunction with either Induction or Synchronous motors should be used.

For example, in applications where they are directly connected to high speed mechanical equipment, such as compressors. The choice between an induction motor and a synchronous motor could be determined by the drive rating. Where synchronous motors are selected, brushless types should be used.

- 3.3.5 Where variable frequency converters are retrofitted to an existing induction motor, the revised system shall be analysed to ensure that the motor will not overheat at full speed rated operation or at any other speed in its operational range.

Refer also to 3.3.2. Unless located in a hazardous area, the assurance of rating under various load conditions may be by manufacturers declaration supported by the appropriate manufacturers calculation.

Generally, existing motors are modern class F insulated machines which have been shown by experience to suffer no insulation failures when supplied from inverters. Some Class A machines, however, have suffered insulation failures in the past.

The increased motor losses due to harmonics produced by inverters should not lead to a derating of existing induction motors for variable speed duty provided a

pulse width modulated (PWM) type of inverter is used and the speed turndown is limited to 20-25%. There is usually a 10% design margin in motor rating and in addition, on class F insulated motors with class B temperature rise (as should be the case for BP installations), there is a further 20°C rise permissible in running temperature available to make full use of the class F insulation. However, the duty rating must be checked by liaison between the inverter and motor manufacturer.

- 3.3.6 Where synchronous motors are retrofitted with a variable frequency converter, the deleterious effects on the synchronous motor of the variable frequency converter output harmonics shall be analysed and taken into account.

Current source VSDs are of the Load Commutated type and synchronous machines, having excitation systems which produce strong back Electro-Motive-Force, lend themselves to this type of VSD. A current source VSD will therefore offer the best system choice.

Variable frequency converters may be retrofitted to existing synchronous motors to permit variable speed operation or soft starting. It may be necessary to fit a shaft encoder to the existing motor and it may be necessary to replace or modify the existing motor excitation controls.

4. DRIVE DESIGN

4.1 Reliability

For each application of a VSD, the reliability of supply output from the VSD should be assessed. In assessing the reliability of particular drive systems their 'Mean Time Between Failure' (MTBF) and the 'Mean Time To Repair' (MTTR) should be compared with the operational availability required for the overall drive/driven system.

Drive systems should be designed to give a minimum operational life of 20 years. The initial assessment of reliability could well be as advised by the manufacturer and this could be based upon a component reliability analysis or more simply may be an overall figure based upon the particular manufacturers experience of failure reports. It is important that if options are being considered, reliability of the different alternatives is compared in a like manner.

As a guide the MTBF of the VSD alone should be at least twice that required for the overall drive/driven system. The MTTR for the VSD should be less than the MTTR for the driven equipment.

4.2 Rating

- 4.2.1 Variable speed controllers, except those intended only for soft starting, should be continuously rated for the maximum power demand of their respective motor drives.

Where the driven equipment may be expected to be uprated, the power rating of the VSD may be rated above that required by the existing drive. Where the starting



conditions dictate that high torques are required which are commensurate with high currents, the current rating for this condition may dictate that the power rating of the VSD should again be greater than the motor rating.

- 4.2.2 Soft start variable frequency converters intended for use on a number of large machines should be rated for the starting load of the largest machine on a particular system.

Under some circumstances the VSD could be used as a soft start for a number of drives which would be started unloaded and then transferred to fixed frequency operation. The VSD may be used as a permanent drive for one of the series as a 'topping' controller and therefore under such arrangements the VSD would need to have a power capability related to the process demand needs rather than purely a starting duty.

4.3 Harmonics

A power systems harmonic analysis should be carried out where a solid state type variable speed drive system (or a number of systems) of significant rating is intended to be installed.

The assessment of VSD power rating for significance to power system harmonics is dependent upon a number of factors which include:-

- Voltage of supply
- Number of pulses of the converter
- The amount of harmonic generation plant already part of the installation.

The need for a harmonic analysis should be assessed on the basis of a sitewide system. Each individual VSD will comprise only a component part of the overall study.

For guidance on the acceptable limits for power system harmonics, refer to BP Group [RP 12-3](#).

(See also 4.4 and 4.8) In any of the analyses involving harmonics, the power system can often constitute a major source of error owing to the scarcity of accurate data concerning harmonic impedances. Contractual arrangements with VSD driven equipment vendors should consider this issue at the outset and have contingency plans and/or budgets as necessary.

4.4 Transient Torque

The effects of transient torque on couplings and other parts of the driven equipment shall be analysed for the conditions of starting, step speed change and stator terminal short circuits.

Refer to 3.3.1. The responsibility for torsional analyses should normally be undertaken by the co-ordinating manufacturer or as a sub-contract of that manufacturer with the co-ordinating contractor accepting the responsibility for defining the parameters and deploying the results. It may be possible that the arrangements for torque analysis could be combined with a power system harmonic analysis. Whatever the contractual arrangements for delivery of studies, (power

system harmonics or torsional/vibration) there should be a clear understanding of the purpose of the studies, their relationship to the purchase contract for the VSD-motor-driven-equipment and the responsibilities of the manufacturer. (See also 4.3 and 4.8)

A short circuit at a synchronous motor stator terminals may give rise to transient air gap torque values of several times full load torque when the synchronous motor is operating at a speed of less than mains nominal synchronous speed. The magnitude of short circuit torque can be calculated by motor manufacturers using variations of a method described by Kirschbaum, IEEE Transactions 65, February 1945, Volume 64.

Where torque pulsation is considered to be a potential problem, special system designs could be considered. (e.g. The motor may be provided with a dual or quadruple stator winding fed from a 12 pulse or 24 pulse inverter output stage.)

4.5 Motors

The machine construction for those machines supplied by VSDs should be based upon BP General Engineering Standards BP Group [GS 112-3](#) or BP Group [GS 112-4](#) detailing the requirements for LV and HV induction machines respectively.

Under some circumstances the machine receiving supply from a VSD may need to be more special and the BP Group Guidance for Specifications may need to be supplemented by additional sheets which detail any particular requirements. Such particularisation may be relatively minor as in the case of multi winding induction motors, through wound rotor induction motors and synchronous motors to specifying the requirements for d.c. motors.

4.6 System Protection

System protection arrangements should take account of both the harmonics if applied to the VSD input and the output frequency range if applied to motor protection.

Electrical protection relays are generally arranged to be suitable for accurate duty within specified frequency limits, typically 47 to 52 Hz. Some electrical protection relays may be affected by the voltage supply wave shape which may contain multiple crossing of the zero line.

4.7 Controls

4.7.1 The control system for the variable speed drive should be developed in conjunction with the requirements of the driven equipment and the process stream of which it forms part.

Critical speed points will need to be transversed without delay and will be 'locked out' as far as operating points are concerned. Particular attention should be paid to speed ramp times to be assured that the system accelerates through critical points but does not introduce severe shock to any critical processes.

- 4.7.2 If the motor drive operates at a frequency and voltage compatible with the available mains supply, consideration should be given to the provision of by-pass arrangements around the variable frequency converters of essential a.c. motor drives. This is in order to permit the drive to be operated at fixed speed in the event of converter failure.

Where this feature is provided, particular attention should be paid to the method of motor starting as this may be suitable for VSD starting but could cause problems when started direct on line. Similarly, the electrical protection provisions need to be suitable for the direct connection of the motor to the mains.

- 4.7.3 Where the VSD may be supplying an electrical submersible pump, controls and alarms should be specified for the particular duty and shall be subject to approval by BP.

The specification for Electrical Submersible Pump (ESP) duty should include requirements as follows:-

- (a) *Minimum torque at pump standstill. (Often $1.5 \times T_{FL}$ is specified to overcome pump stiction.)*
- (b) *A readily accessible reversing control for the VSD is often required because at ESP commissioning a reverse operation period is often required.*
- (c) *The start-up ramp time for the ESP is generally required to be reasonably fast (say 1 to 3 seconds) in order to rapidly transverse the many critical speeds which will exist. (However there is considerable damping in the system when the entire pump is submerged in fluid)*
- (d) *There is generally the requirement for chart monitoring of the VSD current as part of the well assessment.*
- (e) *In view of the relatively short life expectation of the ESP there may be particular electrical parameters which could be monitored as part of the VSD provisions which could be cost effective in assisting failure diagnostics. (e.g. The provision of an electronic buffer which would contain phase current information spanning the period just prior and during an overcurrent trip.)*

The application of VSDs to ESP duty represents a highly specialised subject with considerable expenditure invested in the ESP installation. As this may be seen as a weak link and the purpose of the VSD is to prolong life expectation, BP should be involved in the detail of the application. It should be emphasised that the VSD has the potential to shorten ESP life should overspeed, overvoltage, overcurrent conditions persist.

4.8 Critical Speeds

Torsional and lateral analyses should be carried out for both the drive and driven equipment to identify any critical speeds or critical harmonics in the VSD.

(See also 4.3 and 4.4)

This analysis is considered to be mandatory for any drive to be supplied by a VSD. Operation at any critical speed within the operating range of the VSD should be prevented.

This type of analysis can often offer useful information to the VSD designer who may be able to adjust the internal control systems to avoid resonance conditions.

It is essential that the responsibility for Power System-VSD-Motor adequate performance rests squarely with the system vendor (either the VSD manufacturer taking the lead or the pump/compressor/fan vendor taking the lead). BP will necessarily be involved in supplying Power System information as required.

5. CABLING

5.1 General

Cabling from VSDs to motors should be 3 core.

The preference for 3 core cables is expressed in order to avoid the problems associated with magnetic effects, sheath voltages, unbalanced loadings (in parallel phase conductors) and sheath circulating currents which may be encountered in single core cable systems.

Multiple 3 core cables are acceptable provided the number does not exceed 3 and provided the VSD and motor terminal boxes are sufficient for an easy and unstressed arrangement.

5.2 Single Core Cables

5.2.1 Where single core power cables are used between the variable speed controller and the motor, the cables shall be run in trefoil three phase groups. Where there is more than one cable per phase, the trefoil groups shall be oriented to ensure reasonably equal current sharing in each cable per phase.

Where perfect balance of current between parallel single core cables is not assured it is advisable to allow an 'unbalance factor' when selecting the cable sizes.

5.2.2 Where single core cables are employed, the standing voltage across any sheath or armour insulation or between sheath and armours of different phases shall be below 25V. During any type of power system fault condition the voltage between the same points should be below 430V. (Or 650V if the circuit under fault has electrical protection of the high speed type. e.g. Instantaneous or high set overcurrent which will trip from 650V or less with no delay other than the relay pick-up and breaker trip time.)

The limiting voltages specified for fault conditions are generally selected as those which were acceptable to The International Telegraph and Telephone Consultative Committee for installing telephone lines without specific measures for personnel protection. The standing voltage limit is arbitrarily selected and is considered reasonable for Industrial installations. A value of 65V is often used within the supply industry as a limit for standing voltages at cable sealing ends but this is considered too high for application where the insulation between cable armour and other metalwork may be on a transformer cable box or switchgear cable box located within an accessible substation.

- 5.2.3 Metallic cable sheaths and the armouring of any single core power cables should be of non-magnetic materials.

This provision will avoid magnetic loss effects which may derate the cable.

- 5.2.4 Where single core solid bonded cable systems are used, cable sheathing and armouring cross sections shall be designed for any circulating currents and the cables shall be adequately derated to allow for the heating effects of such circulation currents.

Particular emphasis should be placed upon the harmonic effects which are generally considered to be considerable from VSD output current wave forms.

6. EQUIPMENT TESTING

6.1 Motors

For new installations involving VSDs motors should be tested at the manufacturers works in accordance with a testing programme which is Project specific.

The motor tests should include a temperature rise test at full load.

6.2 Variable Speed Drives

Apart from tests appropriate to the VSD in the manufacturers works, Variable Speed Drives incorporating solid state variable speed controllers should be tested together with their motors and driven equipment at either the driven equipment manufacturer's works or other suitable location, after completion of the individual component tests.

Often, VSDs can be considered in two parts:-

- (a) A fixed portion which would comprise all of the power electronics circuits.
- (b) A movable portion which would provide all of the control capability.

The fixed portions can be considered to be sensibly identical components which would exhibit identical responses according to the controllers settings. In a multi machine delivery the fixed portions may therefore be functionally tested using a common controller. However it is imperative that any string testing is undertaken with the permanent controller. Where large equipment is involved, it is often



desirable for the VSD and motor to be 'string tested' together prior to the motor being coupled to the driven equipment. This initial testing would serve to enable most of the VSD controller adjustments to take place prior to the more expensive system string testing and for there to be a proven comparability between the electrical system components.

Where multiple identical VSDs are being ordered, it would be generally sensible to test only the controller in conjunction with the string tests using one of the VSD equipment installations since the fixed portions of the VSD will exhibit identical responses according to the controllers settings.

These additional tests should include:-

- (a) Motor temperature rise test under load across the speed range. Certification of the motor for variable speed duty in a hazardous area shall be subject to approval of the testing methods by an independent certifying authority approved by BP.*
- (b) Motor vibration test across the speed range whilst unloaded.*
- (c) Motor noise test across the speed range.*



DEFINITIONS AND ABBREVIATIONS**Definitions**

Standardised definitions may be found in the BP Group RPSEs Introductory Volume.

Abbreviations

EMF	Electro Motive Force
ESP	Electrical Submersible Pump
MTBF	Mean Time Between Failures
MTTR	Mean Time to Repair
PAM	Pole Amplitude Modulation
PWM	Pulse Width Modulation
RMS	Root Mean Square
VSD	Variable Speed Drive



LIST OF REFERENCED DOCUMENTS

A reference invokes the latest published issue or amendment unless stated otherwise.

Referenced standards may be replaced by equivalent standards that are internationally or otherwise recognised provided that it can be shown to the satisfaction of the purchaser's professional engineer that they meet or exceed the requirements of the referenced standards.

International Standards

IEC 79-014	Electrical Installations in Explosive Gas Atmosphere (other than mines)
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British Standards

BS 5000 Pt 16	Rotating Electrical Machines with Type of Protection 'N'
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BP Group Documents

BP Group RP 12-3	Power System Design
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BP Group RP 12-2	Electrical Equipment in Flammable Atmosphere and Combustible Dusts
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BP Group GS 112-3	LV Induction Motors
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BP Group GS 112-4	HV Induction Motors
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