

Permanent Magnet Motor Safety

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Introduction

In electrical submersible pump (ESP) systems, two motor technologies provide power to the pump: the AC induction motor (IM) and the permanent magnet motor (PMM). The IM has been the industry standard since 1916. It evolved over time with many improvements and is a mature technology in 2021. PMM, a younger technology originating in the 1990s, also evolved in the early 2000s and has gained global commercial acceptance since 2010. PMM requires more precautions due to the construction and physics of the motor and how it generates voltage. [Figure 1](#) provides a brief comparison of the two motor technologies.

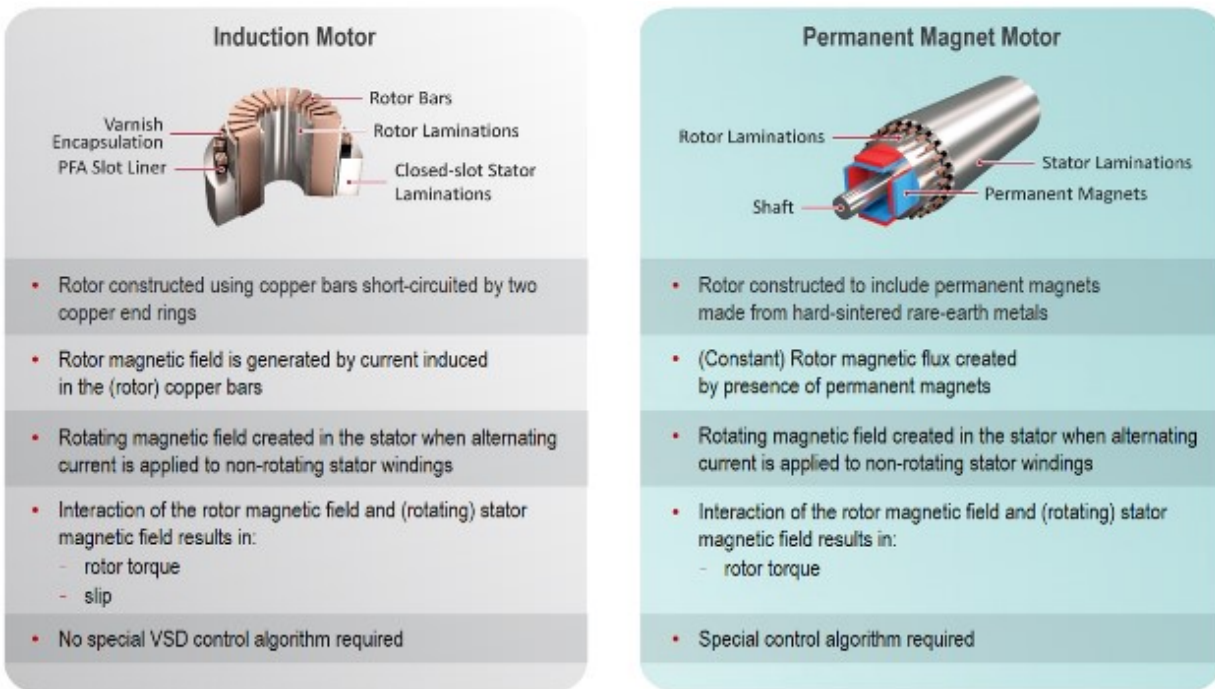


Figure 1—Comparison of Induction and Permanent Magnet Motors

In both IM and PMM, the ability to perform work arises from the torque produced by a rotating shaft resulting from the attraction of rotating electromagnetic poles in the stator to corresponding opposite magnetic poles in the rotating rotor. It is the sequence of three-phase currents flowing through the stator windings, which creates the rotating stator magnetic poles, although the physical stator itself is stationary. The poles on the rotor are created in fundamentally different ways.

- In the case of the IM, the stator magnetic field rotating relative to the rotor induces an opposing current in the rotor, which in effect acts like secondary windings, much like a transformer. This rotor current creates electromagnetic poles on the rotor. This current consumes a significant amount of energy and is a major source of the IM efficiency losses.
- Although the PMM has many of the same contributors to loss of efficiency (such as windage and stator core losses), the rotors do not require additional magnetization as they are already magnetized per the specifics of their design and the use of permanent magnets. Due to this elimination of a large source of waste power consumption, the PMM can run much more efficiently than the IM.

One of the implications of this is that the PMM will typically have a much lower idle current than the IM. Whereas an IM may have an idle current of around 35–45 % of the nameplate rating when operating at nameplate voltage, the PMM may have only around 5–10 % of the nameplate current. Exact details of PMM design will vary between suppliers.

In both IM and PMM, the poles on the rotating rotor cause an internal voltage to be generated in the stator winding, known as the electromotive force (EMF). In an IM, if the shaft rotates while the motor is disconnected from any external power source, only the residual magnetic field in the steel laminations is available to generate EMF. In most applications, this residual magnetism will be negligible such that there is no hazardous level of EMF generated, although it is known for back-spinning IMs to generate hazardous voltage. However, EMF will be generated in a PMM any time that the shaft is rotated as the rotor poles, which are magnetically strong, are always present. This EMF will be proportional to the shaft rotational speed regardless of the direction of rotation.

In a conventional well application (oil, gas, water, utility), well fluids moving up the casing-tubing annulus (kick or annular injection) or down the tubing (draining or injection through the production tubing) and then through the pump can cause the shaft to rotate, and thus the PMM to generate EMF. The faster the rotation, the higher the generated voltage that can lead to various electrical hazards, shock, burns, or arc flash.

Despite the EMF associated with PMM technology, their benefits in energy and CO₂ savings and higher power density cannot be ignored. With proper organizational capability and operational excellence, the technology can be used safely on a routine basis. The purpose of this document is to provide recommendations and information to assist with this task.

Permanent Magnet Motor Safety

1 Scope

This document serves to emphasize safety aspects and recommended practices concerning the handling, installation, trouble shooting, operation, and pulling of permanent magnet motors (PMMs) used in subsurface and surface artificial lift pumping systems.

This document does not replace any other specific safety documentation; national and/or local electrical regulations take precedence.

Subsurface systems entail the motor located downhole with the pump. Centrifugal pumps are historically called an electrical submersible pump (ESP). A progressing cavity pump (PCP) mated with a downhole motor with or without a gear reduction unit is typically called an electrical submersible PCP.

For this recommended practice, [Figure 2](#) will be used as reference for a high-voltage conventional ESP system. The submersible system may have a pump that is centrifugal (default), co-helical axial, progressing cavity, gear, vane, or other type of rotational pump. The motor will be of rotational nature to drive the aforementioned pumps and of permanent magnet design.

There are many types of equipment configurations available for PMM operations. Configurations included in this document are listed in [Table 1](#).

Table 1—Deployment Types

Deployment	RIH	POOH	Informative
Conventional	8.4	9.12	F.2
Cable unit	8.5	9.13	F.3
Through tubing: threaded or coupled tubing	8.6	9.15	F.4
Through tubing: coiled tubing with external cable	8.7	9.16	F.5
Through tubing: coiled tubing with internal cable	8.8	9.17	F.6
Docking station	8.9	9.18	F.7
Surface PMM	8.10	9.19	F.8
Downhole driven PCPs			Annex G

Each of these system configurations will have various considerations that shall be made to ensure personnel safety. Some are common to all PMM operations, whereas others will be unique to the given configuration.

- Surface pumping deployments have limited exposure to electrical hazards because the motor is at surface and its shaft or linkage to the pump system can be locked.
- Some deployments install the pump after the motor, and so unplanned motor rotation does not occur when tripping the motor.

In the case of linear submersible pumps, the pump is reciprocating (vertical motion) and is driven by a linear PMM comprising an armature and permanent magnet translator. The armature is the equivalent to the stator, and the translator is the equivalent to the rotor of a conventional ESP. Downhole linear PMM systems are not expressly included in this document as the force required from the fluid to lift the motor and pump is unlikely to result in motor voltage. However, the supplier should be consulted and the principles in this document applied.

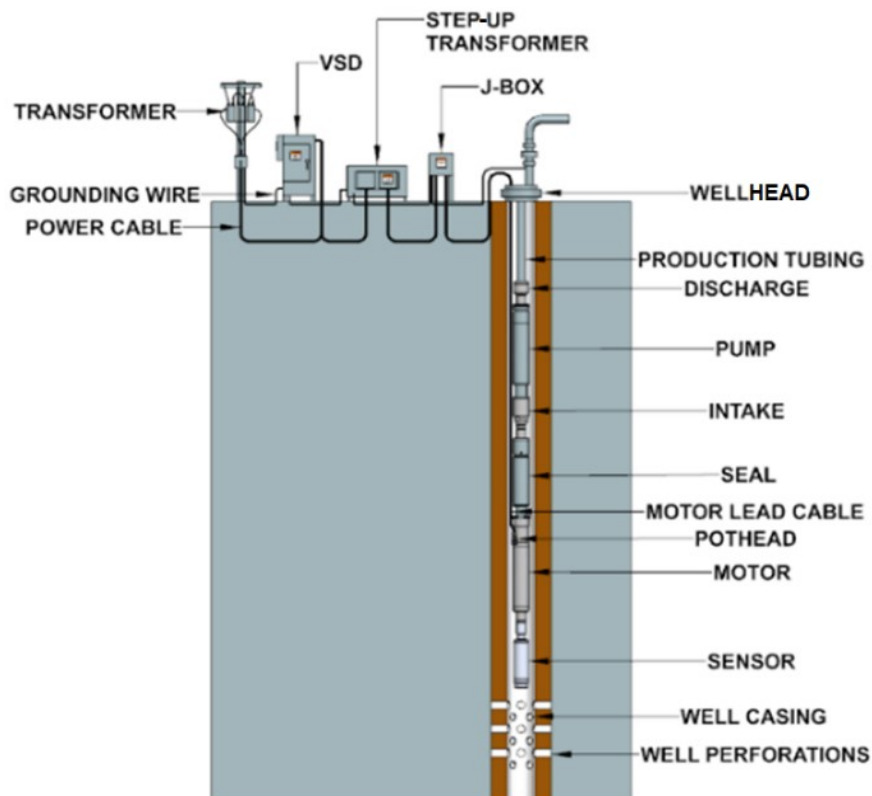


Figure 2—Typical High-voltage Electrical Submersible Pump System

After an introductory review of the nature of risks potentially arising from the use of PMMs (see Nature of Risks and Approach to Safety), this document addresses the main operational tasks involved as laid in the table of contents and shown in Figure 3. The annexes provide detailed supporting information.

2 Normative References

The following documents are referred to in the text in such a way that some or all content constitutes requirements of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any addenda) applies.

API Recommended Practice 59, *Recommended Practice for Well Control Operations*

API Recommended Practice 500, *Recommended Practice for Classification of Locations for Electrical Installations at Petroleum Facilities Classified as Class I, Division 1 and Division 2*

API Recommended Practice 505, *Recommended Practice for Classification of Locations for Electrical Installations at Petroleum Facilities Classified as Class I, Zone 0, Zone 1, and Zone 2*

IATA ¹, *Dangerous Goods Regulations (DGR)*

IEC 60079-0 ², *Explosive atmospheres—Part 0: Equipment—General requirements*

¹ International Air Transport Association, 33, Route de l'Aéroport, PO Box 416, 1215 Geneva - 15 Airport, Switzerland, www.iata.org.

² International Electrotechnical Commission, 3 Rue de Varembe, PO Box 131, CH-1211 Geneva 20, Switzerland, www.iec.ch.

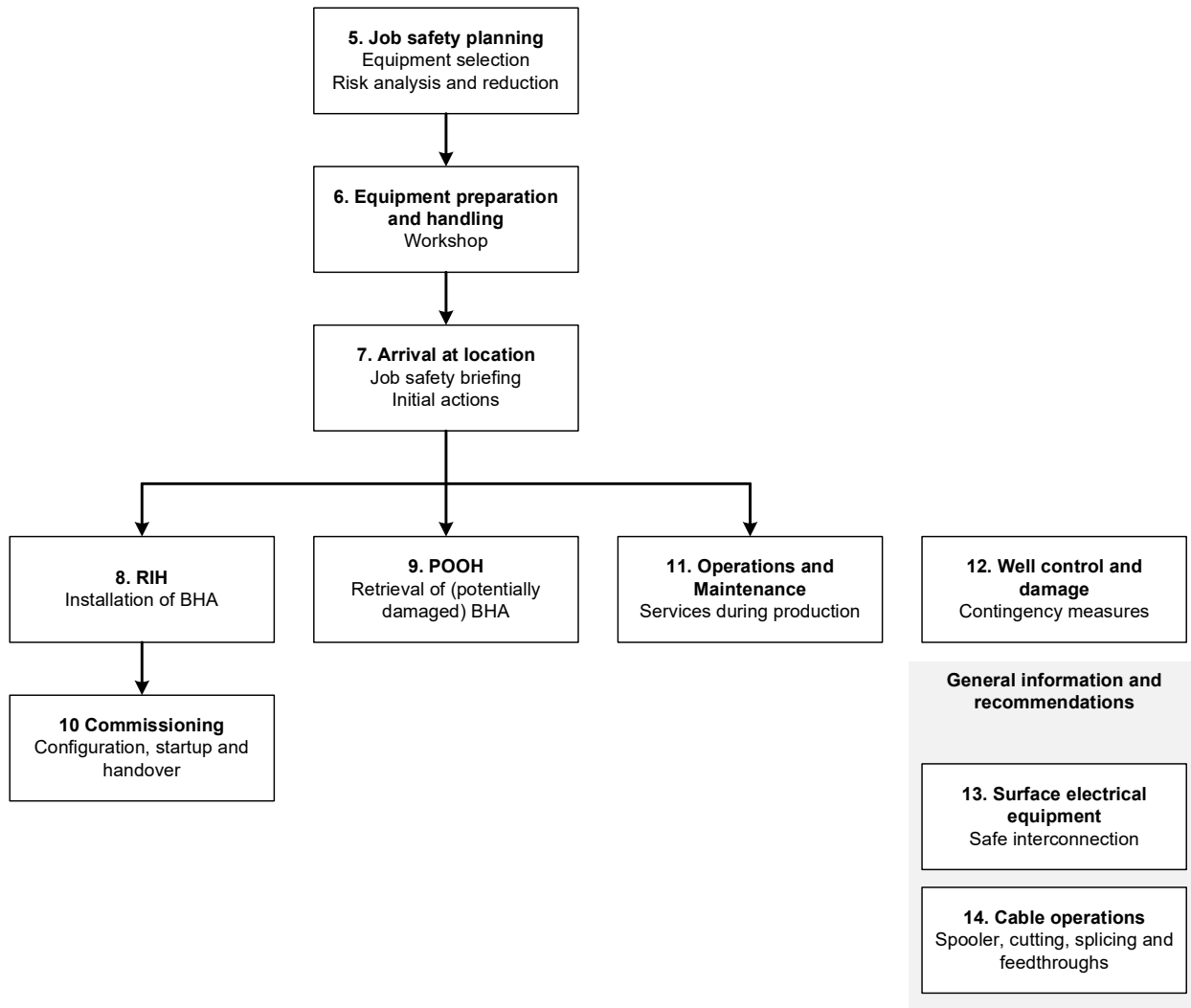


Figure 3—Operational Flow of Document

3 Terms, Definitions, Acronyms, and Abbreviations

3.1 Terms and Definitions

For the purposes of this document, the following terms and definitions apply.

3.1.1

access barrier

barricade

A physically delineated and/or signed separation of an electrical working area limited to task qualified persons.

EXAMPLES:

- The cable reel exposed ESP power cable leads. The cable reel is part of the circuit.
- The point at which a splice is being made.
- Installation of an electrical cable feedthrough at the wellhead.

NOTE Access barrier is not the same as a barrier to flow and both type of barrier may be used during PMM installation and operations. API 59 has practices to prevent uncontrolled flow to surface and uses the term “barriers to flow” where at least two levels of protection are needed. This is especially true during workovers, so for example, 1) kill fluid and 2) blowout preventer (BOP) serves as the two barriers. Some of these same devices/methods may be used as flow control that is critical to limit unplanned motor rotation (see 5.4).

3.1.2

approved grounding point

An electrical connection point or structure capable of carrying fault currents having low resistance to ground and so is equipotential to the wellhead.

NOTE The operator selects an approved ground point considering coatings, corrosion, or other factors that may interfere with the grounding.

3.1.3

arc flash

A phenomenon where a flash-over of electrical current leaves its intended path and travels through the air from one conductor to another, or to ground.

3.1.4

arc flash hazard

A source of possible harm associated with the release of energy caused by an arc flash, where the approach limit to an arc source is the distance at which the incident energy equals or exceeds 1.2 cal/cm^2 (5 J/cm^2).

NOTE See also thermal burns and [Annex H](#) for detailed discussion.

3.1.5

backspin

Rotation of the pump and motor opposite to the operational sense of rotation typically caused by fluid draining or being injected down through the tubing and pump.

NOTE Backspin will cause a PMM to generate voltage and be a potential electrical hazard.

3.1.6

bottom hole assembly

BHA

The ESP equipment deployed into the well, principally comprising pump, motor seal, motor, and sensors.

3.1.7

braided line

A multistrand wire rope, typically steel, which is stored on a small winch unit and is used to deploy equipment into a well bore.

3.1.8

cable deployed ESP

A motor, seal, and pump attached to a weight-supporting ESP power cable or weight-supporting integral tubing and ESP power cable, and progressively run together within the tubing into the well.

3.1.9

cable reel

The metal or wooden reel (drum, spool) on which the ESP power cable is stored prior to deployment in the well or after retrieval from the well.

3.1.10

casing annulus

The annulus between the well casing and well tubing with attached bottom hole assembly (BHA).

3.1.11**centrifugal pump**

A kinetic energy hydraulic pump where centrifugal force is used to discharge fluids from the pump.

NOTE A pump stage comprises a rotating impeller within a fixed diffuser inside the pump housing. Centrifugal pumps are designed with axial flow, radial flow, or a mixed flow stage. Centrifugal pumps will act as hydraulic motors (turbines) when fluid is pumped through them, such as during backspin.

3.1.12**closed phase**

A motor phase terminal that has an external electrically conducting path to another motor phase terminal, and so forms a circuit that will carry current when the motor rotates.

EXAMPLE A shorting link between two ESP power cable phase conductors in the cable reel, or a ground fault in each of two motor phase conductors.

3.1.13**cogging torque****detent torque**

An internal force between the magnets of the rotor and the stator laminations pulling the shaft of an unenergized motor to any of a number of a stable positions.

NOTE Cogging torque prevents free rotation of an unenergized motor and makes it difficult to turn manually.

3.1.14**coiled tubing**

A continuous tubing that is sufficiently elastic to allow it to be delivered to the wellsite on a large reel and unwound into the well.

3.1.15**commissioning**

The phase of work between installation of the ESP in the well during run in hole (RIH) and handover to the operator after satisfactory startup pumping.

3.1.16**conduit box**

Electrical supply conduit outlet body with a gasket cover.

NOTE In the United States, conduit boxes come in several configurations with type designator left (LL), right (LR), bottom (LB), top (T), and continuous (C). These serve the same connection purpose as the vented junction box (JB) but are located at the wellhead in the hazardous area.

3.1.17**continuous monitoring**

The use of instrumentation to continuously monitor the ESP power cable for signs of unplanned motor rotation.

3.1.18**electrical cable feedthrough**

A device for or means of continuing the ESP power cable through the wellhead or a downhole packer in a gas and pressure-tight manner, with or without a cable joint.

3.1.19**electrical isolation**

Prevention of incidental contact with cable conductors using insulation such as tape or a protective enclosure.

3.1.20**electrical line
e-line**

A multistrand wire rope, typically steel, formed around one or more insulated electrical conductors, which is stored on a winch unit and is used to deploy electrical equipment into a well bore and operate it.

3.1.21**electrical submersible pump
ESP**

A downhole pumping system comprising an electrical motor, a motor seal to protect against well fluids, and a connected pump.

NOTE Historically, the term ESP was synonymous with induction motor (IM) and centrifugal pump. Over time, it has expanded to include a variety of positive displacement pumps [PCP, vane, gear, co-helical axial, axial screw, and reciprocating rod pumps (RRPs)] and motor designs [PMM, linear IM, and linear synchronous motor]. Because vendors loosely call any pump downhole driven by an electrical motor an ESP, the term is often prefixed with or without hyphenation to distinguish it from centrifugal pumps, such as ES-PCP or ES-LRRP.

3.1.22**electrical system**

The series-connected electrical components of the electrical pumping system from power supply to PMM.

NOTE Typically, some or all of a utility supply transformer/generator, variable speed drive (VSD), step-up transformer and PMM, with all intermediate connecting cables, JBs, and switchgear.

3.1.23**electromotive force
EMF**

The motor or generator internal voltage created by the rotor's rotating magnetic field passing over the stator windings.

NOTE The EMF is the same whether acting as a motor or as a generator and is directly proportional to the shaft speed. During factory no-load testing of a motor, the recorded motor terminal voltage is very close to the EMF.

3.1.24**energized conductor
live conductor**

A cable conductor that is carrying voltage and/or current.

3.1.25**equipotential bonding zone**

A zone where all simultaneously accessible electrically conductive parts are electrically connected to prevent hazardous voltage developing between them.

EXAMPLE The VSD enclosure, step-up transformer enclosure and vented JB are normally all connected to the approved grounding point by dedicated protective grounding conductors of adequate cross-section to carry any ground fault current with low-voltage differences.

3.1.26**ESP power cable
ESP cable**

Three-phase electrical cable, including the motor lead extension (MLE), running from the motor terminals through the wellhead and to the vented JB or equivalent at the surface.

NOTE 1 Cables may contain additional conductors, such as ground and communications wires. Cables are typically armored using metal [stainless or galvanized steel tape wrapping, or tubing encapsulated (TEC)], which is electrically conductive or nonmetal (polyfluoroalkyl or other polymer material).

NOTE 2 Composite tubing with embedded conductors is not considered in this document.

3.1.27**forward spin**

Rotation of the pump and hence the motor shaft caused by fluid rising through the pump via the intake and into the tubing.

NOTE Forward spin will cause a PMM to generate voltage and be a potential electrical hazard.

3.1.28**ground
earth**

A reference point relative to which voltage of other parts is measured.

NOTE Different ground reference points may have voltage differences.

3.1.29**ground conductor**

The conductor used to connect equipment to an approved grounding point.

3.1.30**harm**

Physical injury or damage to health or environment/equipment.

3.1.31**hazard**

A source of possible harm and, more particularly, electrical shock, sparks, or arc flash.

3.1.32**hazardous area
classified area**

An area, typically encompassing the wellhead, in which flammable vapor is often present and which may be ignited by an electrical spark, resulting in fire and/or explosion.

NOTE The size of the hazardous area is determined by the operator, typically based on API 500, API 505, IEC 60079, or other recognized area classification/zone methods.

3.1.33**hazardous voltage**

A voltage difference that when applied across the human body can cause harm.

NOTE Hazardous voltage is considered to be greater than 50 V AC (alternating current) with dry uninjured hands. Working with wet or injured bare hands reduces the hazardous voltage threshold and is not a safe practice.

3.1.34**hydraulic motor**

A machine whereby fluid flow through it will cause its shaft to rotate or reciprocate.

3.1.35**hydraulic pump**

A machine whereby rotating or reciprocating its shaft will cause fluid to flow through it against an external pressure.

3.1.36**induction motor****IM**

An electrical motor in which the rotor magnetic field is induced from the stator magnetic field created by the stator magnetizing current.

NOTE In principle, an unenergized IM will not generate voltage during unplanned motor rotation. However, it is known that hazardous voltage is sometimes generated by an IM due to residual magnetization of the rotor laminations. In this regard, the recommended practices in this document can also be useful for IMs.

3.1.37 **instrumentation** **meter**

Electrical equipment, fixed or portable, used to make measurements on the surface electrical system from the VSD output to the ESP power cable and their connections.

NOTE Instrumentation used for PMM systems typically has special characteristics. See [Annex B](#).

3.1.38 **job safety briefing**

The safety briefing meeting at the wellsite given by the responsible person to all relevant personnel prior to commencement of work.

NOTE Informally referred to as the job safety analysis, tailgate meeting, toolbox meeting, or pre-work meeting.

3.1.39 **job safety plan**

The detailed PMM hazards risk assessment and mitigations prepared prior to any intended work.

3.1.40 **junction box** **JB** **terminal box** **terminal chamber**

An electrical enclosure with lockable door or fixed cover used to connect power cable and provide protection from incidental contact.

3.1.41 **linear permanent magnet motor**

An electrical motor that has had its stator and rotor “unrolled” flat, producing a linear force along its unrolled circumference instead of producing torque (rotation).

3.1.42 **live-test-live**

A method for verifying proper instrument operation when testing for absence of voltage.

NOTE See [14.3](#).

3.1.43 **lockout, tagout** **LOTO**

A system of electrical working in which multiple-key locks are used to isolate electrical equipment, whereby all workers involved have their own key and so can be assured that their isolation cannot be undone by another worker.

3.1.44 **maintenance**

Any activity that involves accessing the electrical system after installation and commissioning are first completed.

EXAMPLE Inspection, preventative servicing, repairing.

3.1.45 **motor lead extension** **MLE**

That portion of the ESP power cable connected directly to the motor terminals and adapted for the limited space and higher temperatures found near the motor.

3.1.46**motor short-circuit current**

The current generated during unplanned motor rotation by a PMM with the ESP power cable shorted at surface.

3.1.47**open phase**

A motor phase terminal that has no external electrically conducting path to another motor phase terminal and so may carry voltage, but does not form part of a circuit that can carry current.

EXAMPLE An insulated end of an ESP power cable phase conductor.

3.1.48**operator**

The organization responsible for all well operations; is not necessarily the well owner.

3.1.49**pack-off feedthrough**

An electrical cable feedthrough using a continuous cable sealed with elastomer glands.

3.1.50**penetrator**

An electrical cable feedthrough using a cable connector or joint.

3.1.51**permanent magnet motor****PMM**

An electrical motor in which the rotor magnetic field is provided by permanent magnets.

3.1.52**point of working**

The area spanning all simultaneously accessible electrically conductive parts at the point where work is being performed, including a floor or soil.

EXAMPLE Performing a cable splice, testing at the end of the ESP power cable.

3.1.53**pole**

A north or south magnetic pole on the rotor facing the stator and always in unlike pairs.

NOTE IMs are commonly two poles, whereas PMMs are commonly four or higher poles. For a given shaft speed (rpm), the electrical frequency is proportional to the number of poles.

3.1.54**pothead**

The termination of the MLE that is used to attach it mechanically and electrically to the motor.

3.1.55**progressing cavity pump****PCP****progressive cavity pump**

A type of positive displacement pump, in which fluid is transported in travelling cavities formed between the rotating pump rotor and the pump stator.

3.1.56**protective grounding**

Grounding in the electrical system for protection against electrical shock.

NOTE Protective grounding is subject to company, local, state, and national regulations where applicable. These may be more restrictive or less restrictive than the basic requirements of protective grounding in this document.

3.1.57**pull out of hole****POOH**

The process of retrieving the BHA from the well bore.

3.1.58**responsible person**

The person designated by the operator who has responsibility for the safe performance of all operations at a well, to whom all persons arriving at a wellsite report and who will conduct the job safety briefing.

NOTE There is no industry standard terminology for this position. Other commonly used terms include the following:

- company representative;
- company man;
- project lead;
- person in charge;
- senior responsible person;
- authority having jurisdiction.

These terms may vary in scope according to operator and apply to a field or individual well.

3.1.59**risk**

The degree of likelihood that a hazard will cause harm, evaluated in the context of reasonably foreseeable events including human factors.

3.1.60**run in hole****RIH**

The process of deploying the BHA into the well bore.

3.1.61**shock hazard**

Possibly harmful effects of an electrical current driven through the human body by hazardous voltage.

3.1.62**simultaneous operations****SIMOPS**

Situations where two or more operations or activities occur at the same time that may interfere with or oppose each other and may involve risks that are not identified when each activity is considered by itself.

Warning—Of particular concern in this document is a PMM activity (for example, splicing) and another at the same time that has the possibility to cause unplanned motor rotation (for example, retrieving a submerged wireline plug).

3.1.63**slick line**

A single-strand wire, typically steel, which is stored on a small winch unit and, while maintaining a pressure seal when run through pressure control equipment, is used to deploy equipment into a well bore.

3.1.64**splice**

An insulated electrical joint between sections of ESP power cable.

3.1.65**spooler**

The winch unit that carries the ESP power cable reel and unwinds/rewinds the cable between reel and well during RIH and POOH.

NOTE Typically truck or trailer mounted when used on land, and skid mounted when used offshore.

3.1.66**step-up transformer**

An isolating transformer connected to the output of a low-voltage VSD, which raises the drive voltage to the voltage required to operate the downhole motor.

EXAMPLE A 480 V primary tap with typical multiple secondary taps from 2000 V to 4000 V.

NOTE Isolation allows continuing operation when there is a single ground fault on the ESP power cable or motor and provides additional safety if there is no ground fault and sometimes referred to as an ungrounded or IT (isolated terre) system. Systems that do not use a step-up transformer sometimes use an isolation transformer at the input to the VSD. These systems are sometimes referred to as an ungrounded or IT system.

3.1.67**stop work authority**

Authority delegated by the responsible person to other persons to call for an immediate stoppage of work if required in the interests of health, safety, or the environment.

3.1.68**supervised training**

Training that requires field mentoring and assessment prior to task qualification.

3.1.69**supplier**

Provider of equipment and/or services.

NOTE Also known as vendor, manufacturer, original equipment manufacturer, service provider, equipment provider.

3.1.70**surface pigtail**

The length of ESP power cable between the wellhead feedthrough and the vented JB; may be a separate piece of cable according to feedthrough type.

3.1.71**task qualified person**

A person who by a combination of documented supervised training and practical experience has demonstrated competency to perform specific tasks.

3.1.72**thermal burns**

Harm from an arc source wherein fault currents are low and the main hazard is injury from heat (incident energy).

NOTE Other causes of thermal burns are not considered in this document.

3.1.73**tubing encapsulated cable**

ESP power cable conductors encapsulated in small diameter steel tubing that is used in cable deployed systems.

3.1.74**unplanned motor rotation**

Rotation of the motor shaft by external means that results in the motor acting as an electrical generator.

3.1.75**variable speed drive****VSD****variable frequency drive****adjustable speed drive****adjustable frequency drive**

Surface power electronics equipment used to control the downhole PMM speed directly or indirectly.

NOTE See [Annex J](#) for further information on VSDs in relation to PMMs.

3.1.76**vented JB****vent box**

The first connection point in the nonhazardous area between the surface electrical equipment and the surface end of the ESP power cable.

NOTE 1 The JB design is vented for airflow to prevent the accumulation of gas that may migrate up the ESP power cable and onward to other surface equipment and risk explosion. It provides an access point for isolating the connection between the two and for measurement. The location may vary according to vendor and operator procedures and the equipment used.

NOTE 2 Some wellhead feedthroughs block all gas migration, and the JB is not required to be vented.

3.1.77**well kick**

An unpredictable and unplanned surge of fluid, gas, or fluid and gas from the well resulting in forward spin.

3.1.78**well kill fluid**

High density fluid used to load an open well during RIH and POOH to prevent or control well kicks.

3.1.79**wireline**

Slick line, braided line, or electrical line according to context.

3.2 Acronyms and Abbreviations

AC	alternating current
BHA	bottom hole assembly
BOP	blowout preventer
CT	coiled tubing
DC	direct current
DIFA	dismantle inspection failure analysis
EMF	electromotive force
ESP	electrical submersible pump
HMI	human-machine interface
IM	induction motor
IT	isolated terre (French ground/earth)

JB	junction box
LOTO	lockout, tagout
MLE	motor lead extension
PCP	progressing cavity pump
PMM	permanent magnet motor
POOH	pull/pulling out of hole
PPE	personal protective equipment
RIH	run/running in hole
RRP	reciprocating rod pump
SIMOPS	simultaneous operations
SRP	sucker rod pump
TDR	time domain reflectometer
TEC	tubing encapsulated cable
VSD	variable speed drive

4 Nature of Risks and Approach to Safety

4.1 General

In traditional (IM) ESP applications, the power source or line power is considered to originate from a utility or a generator at the surface. Additionally, as outlined in the introduction, a PMM will generate internal voltage when externally forced to rotate, regardless of the direction or its location—surface or subsurface. Surface risk is managed because the equipment can be seen, but subsurface a secondary power source lurks unseen to unaware operators.

4.2 Multiple Sources of Power

Causes of secondary power from forced shaft rotation downhole can include an ESP pump acting as a turbine or a PCP acting as a hydraulic motor. When secondary rotation occurs, any connected surface equipment will be energized even if disconnected from the utility power. The amount of voltage produced is proportional to the speed at which the motor is rotating.

NOTE IMs are known to sometimes generate hazardous EMF from residual magnetism. Practices in this document can also enhance safety in IM installations.

The change from one primary electrical power source to potentially two electrical power sources are significant and shall be considered in all aspects of PMM operations such as installation, maintenance, or pulling the equipment. This additional power source is the primary reason for the creation of this recommended practice.

Any contact with electrical energy can cause severe harm to personnel. This may include electrical shock leading to ventricular fibrillation or burns (internal and/or external) as well as arc flash leading to severe burns (external). Voltage above 50 V across the body is considered hazardous. The sensation of electrical shock typically may occur at low current, for example 5 mA. If there is no ability to prevent motor rotation, then safety protocols shall be put into place to protect the personnel from this contact as PMM rotation can easily cause these levels to be exceeded.

Figure 4 shows an elementary circuit that illustrates that current flowing in a conductor is of itself not a hazard when the conductor is touched. The hazard arises if there is hazardous voltage across the contact points of the body. In this circuit, the supply provides a hazardous voltage relative to ground and across the lamp, and the lamp draws 1 A. A person touching the 110 V side of the supply and standing on the same ground will form a parallel circuit. Assuming a representative hand to foot resistance of $1500\ \Omega$, and no personal protective equipment (PPE) or footwear, potentially 73 mA would flow through the body and cause harm. The same person touching the grounded side of the lamp would have no voltage across the body and no current would flow through the body, resulting in no harm. These parallel circuits formed by body contact are independent of the lamp current.

NOTE This explanation assumes an ideal connected ground for the circuit and the person. In practice, the requirement for a grounded equipotential zone in this document means that any current flowing between ground points in the zone will result in very low-voltage differences and only very low current through the body. In addition, using recommended practice, the operator would be wearing PPE that provides a degree of safety in case of incidental contact with the 110 V conductor.

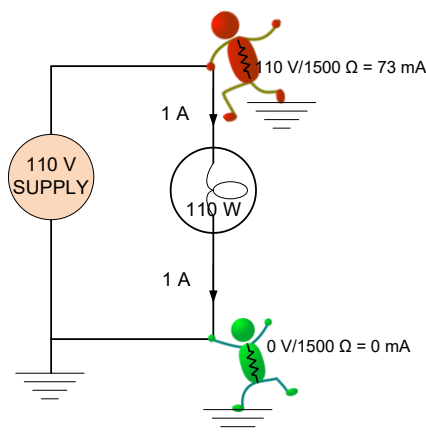


Figure 4—Voltage and Current in Electrical Shock

Caution—Unless otherwise proven, any conductor should be assumed to be energized. Incorrect identification of cabling or incorrect application of measurement instrumentation can lead to a false sense of safety.

Caution—Always assume a PMM is installed in every well with a downhole motor until proven otherwise. Surface equipment and connections are essentially the same for PMM and IM installations. Motor type cannot be determined by inspection; signage and records may be incorrect. The ESP technician should have training as required for making this determination with the operator.

4.3 Unplanned Motor Rotation

4.3.1 General

Causes of external forced rotation are generally related to fluid displacement through the pump, such as during:

- RIH (fluid direction is pump intake to pump discharge);
- POOH (fluid direction is pump discharge to pump intake);
- well kick (fluid direction is pump intake to pump discharge);
- back flow after the system is shut down (fluid direction is pump discharge to pump intake);
- generally, fluid injection (injection through the annular space would cause fluid to move through the pump intake to the pump discharge, whereas injection through the tubing would cause fluid to move from the pump discharge to the pump intake).

These causes result in backspin or forward spin according to the direction of flow.

Another cause is manual rotation of the motor shaft, though generally cogging torque limits the speed to a very low value, and the voltage is nonhazardous.

In this document, all causes of rotation other than from normal pumping operations are termed unplanned motor rotation. Protection against any unplanned motor rotation should be considered as a multitiered approach rather than only one method of protection. See [4.3](#), [4.4](#), and [Section 5](#) for a more detailed evaluation of these tiers.

In an installed system, backspin usually occurs whenever the VSD stops for any reason—power failure, fault, or commanded stop. It frequently commences at higher than running speed, then gradually reduces in speed, coming to a stop after a few minutes to more than an hour.

Caution—In some circumstances, the generated voltage may exceed the ratings of the electrical equipment and cause damage if high speed is not prevented.

Forward spin can arise from well kicks that flood the casing annulus and establish a pressure differential across the pump, or removal of a tubing plug when the casing annulus fluid level is higher than in the tubing, or when a PCP breaks free with reverse pressure present during RIH.

Caution—Pump blockage or, in the case of PCPs, break-out friction, can prevent or delay backspin in an unpredictable manner. PCPs can back spin fast enough to destroy the stator elastomer and exceed VSD ratings unless preventative measures are taken.

4.3.2 Prevention of Unplanned Motor Rotation

The first approach to PMM safety, in addition to any other site- or operation-specific safety considerations, should be to eliminate or limit the potential for unplanned motor rotation (electrical energy generation) to occur. There are many ways of approaching this, and many of the methods may be used in combination to create multiple layers of protection. It is important that any method of preventing motor rotation also allow for it to be tested once it is activated. These methods can vary significantly due to local regulations and operator/equipment supplier guidelines. See [5.4](#) for examples and further details.

4.4 Electrical Protection

4.4.1 General

There is always the potential for any device or method to fail or not be properly used. Gaps may also be present before or after implementation of a given method. Therefore, a safety protocol shall also consider safe electrical work procedures that identify how to properly isolate the PMM as well as provide guidance to select the proper PPE and any other protective equipment to be used during work associated with exposed and potentially energized conductors or electrical system components. Using surface equipment with lockable enclosures and performing associated lockout, tagout (LOTO) is an example of good practice for minimizing incidental contact with the electrical system.

During installation, maintenance, and pulling operations, there are occasions where there may be contact with the electrical conductors (such as drive maintenance, splicing, or electrical checks of the installed system). This contact can lead to significant harm unless appropriate mitigations are put into place. For situations such as drive maintenance, clear and accurate electrical diagrams should be provided to the technician performing the work to provide guidance on any potential power sources and to show that power may be coming from both surface and downhole directions. However, even with diagrams available, all conductors should be considered energized until an electrical safe working condition has been established and proven.

If there is no means of locking the equipment shaft string from rotating, then spot-checking that the conductor is not energized does not ensure safety as the well may flow at any time due to downhole reservoir conditions or simultaneous operations (SIMOPS).

4.4.2 Open and Closed Electrical Submersible Pump Power Cable Conductors

There are two primary ways to address the conductor ends at surface during RIH and POOH:

- a) shorting and grounding the ends;
- b) leaving the ends open but insulated or otherwise isolating the ends to prevent incidental contact.

Both methods can be used as applicable to minimize the electrical risks. However, neither will fully eliminate electrical risks.

In this document, both open or shorted phases may be used depending on the specific work to be performed and the equipment supplier's guidelines for the given operation. Any transitions between the two methods shall be assessed to identify any new electrical hazards that can be created during the transitions, such as sparks or exposure to energized conductors. See [Annex I](#) for further discussion of these two methods.

Warning—It is not recommended to short the leads together and isolate them from ground (for example, using insulation). If there is a ground fault, the shorted connection will not be at ground potential and there is an increased risk of encountering energized conductors. See [Annex I](#) for detailed discussion of open and shorted conductors.

Warning—At no time should only two of the three phases be shorted together. If the motor turns, there will be voltage between the open phase and the shorted phases. If either the shorted phases or the open phase is grounded, the ungrounded conductor(s) will be at full voltage relative to ground. If at a location other than at the cable ends, all three phases may have significant voltage between them or to ground.

4.5 Risk Management

Risk management in this document is based on the following.

- a) Assessment during job safety planning (see [Section 5](#)):
 - 1) engagement of the equipment supplier to evaluate each step of RIH, maintenance, or POOH to determine the best methods for a given operation considering the equipment design, application, and other applicable considerations;
 - 2) prevention of unplanned motor rotation by selection of completion equipment.

Caution—Prevention methods cannot be assumed to be functioning properly unless tested prior to use. Although new when first installed, well conditions on a subsequent POOH may have impaired the device(s) used.

- b) Compliance with all relevant national and local electrical regulations.
- c) Nothing in this document is intended to conflict with applicable regulations. If a conflict does arise, it shall be resolved considering all circumstances.
- d) Completing adequate workshop preparation (see [Section 6](#)) to minimize wellsite risks.
- e) Safety briefing upon any arrival of personnel on location (see [Section 7](#)).
- f) Protection of electrical workers by recommended practices, primarily in cable operations and measurements (see [Section 14](#), [Annex B](#)), PPE ([Annex C](#)) and requiring task qualification (see [Annex A](#)).
- g) Ensuring signage (see [Annex E](#)) informs personnel of hazards.
- h) Using properly rated and applicable PPE, test instruments, and tools for the task (see [Annex B](#) and [Annex C](#)).
- i) Performing LOTO to address both utility and downhole power sources.
- j) Promulgation of PMM safety awareness in the industry.

5 Job Safety Planning

5.1 General

There are two primary parts of job safety planning included in this section. The first involves the initial equipment design and selection. Designing and selecting equipment for safety is important to consider at the beginning as the choices made during this stage will impact all other following steps throughout the lifecycle of the equipment (and potentially the well). The second part of job safety planning is pre-work planning that is done by the personnel performing a given task and the operator (such as RIH, maintenance, or POOH.) Where possible, it is recommended to incorporate the personnel to perform the tasks (or at least one skilled in the task to be performed) in the initial stages of the equipment selection and design so that an iterative job safety planning may be performed. By getting the feedback of those that will perform the tasks, better equipment selection and preparation can occur.

A final job safety plan should be completed by the responsible person before each job that involves exposure of workers to hazards arising from PMM-related work at a wellsite. This job safety plan is specific to the job to be performed whether a new install or basic troubleshooting. Planning for PMM-specific considerations in this document is in addition to normal job planning. For example, monitoring for H₂S is a typical job safety plan requirement but is not explicitly considered in this document.

This section applies to all PMM deployment methods. Additional deployment-specific topics may be found in their respective subsections.

At the conclusion of the planning process, equipment will have been selected for a new install, job procedures prepared and reviewed, and the job safety plan completed, ready to be taken to the job safety briefing upon arrival at location. Some jobs, such as a new install, may require a lengthy planning process. Others, such as troubleshooting of an existing system, may have only a few safety aspects to consider.

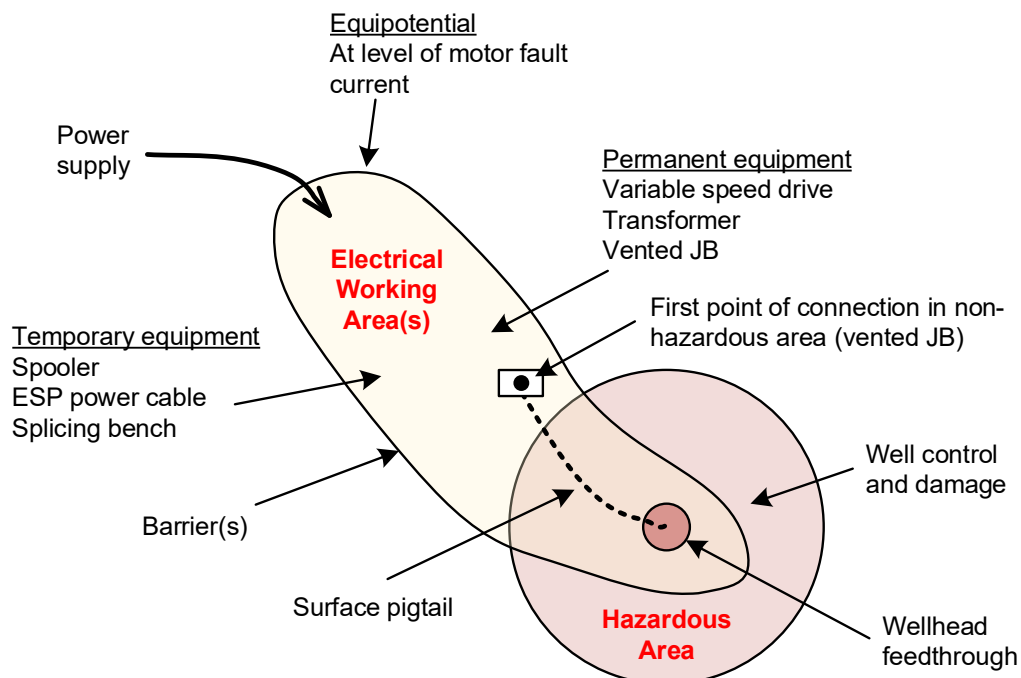


Figure 5—Hazardous and Nonhazardous Areas at Wellsite Location

Figure 5 shows in schematic form the surface equipment and locations where hazards exist and introduces some of the defined terms in this document. The operator defines a hazardous area surrounding the wellhead (the shape and size of which can vary over time). The ESP power cable transitions through the wellhead and continues as a surface pigtail into a nonhazardous but electrical working area. The electrical working area may in practice be more than one area; each area is delineated by an access barrier. The first point of termination of the ESP power cable in the electrical working area is typically the vented JB or equivalent. This is the recommended and usually most convenient point of isolation of the remaining surface equipment from the downhole equipment. During RIH and POOH, the spooler will be located in the electrical working area, and splicing operations may be required. The power supply is disconnected and LOTO during electrical work other than commissioning.

The initial planning discussion(s) should include the jobs that involve exposure of workers to electrical hazards and cover general awareness of PMMs and their risk management (see Section 4). This should include the following information.

- a) Description of the overall job, equipment selection, and the individual tasks needed.
- b) The risks associated with unplanned motor rotation and methods of prevention.
- c) Well control (see Section 12).
- d) Identification of electrical hazards associated for each task.
- e) Shock assessment for tasks involving a shock hazard.
- f) Arc flash risk assessment for tasks involving an arc flash hazard due to prospective short-circuit currents. (At typical currents that motor can generate, the effect of arc flash may be limited to thermal burns.) See Annex H for more information.
- g) Spark assessment—Creating sparks in a hazardous area where flammable gases are present.
- h) Hot work assessment—Does the nature of the work require a hot work permit? If the work to be performed is inside the hazard area and flammable gas exists, then a hot work permit is needed.
- i) Up-to-date electrical diagrams maintained by the operator, with supplier equipment information and clear labelling of electrical power sources.
- j) Understanding that surface equipment has two sources of power—the drive supply and the PMM when rotating.

Warning—The drive supply can be isolated using standard practices, but in most types of deployment, including conventional, there is no downhole means of disconnecting the PMM from the power cable or from the pump attached to it. Consequently, the surface cable from the wellhead can be energized at any time even if it is not terminated at the vented JB.

- k) Work procedures involved, specific equipment precautions and energy source control, specifically PMM EMF.

5.2 Safety Controls

To facilitate the incorporation of PMM recommended practices into existing safety practices, the following topics are listed in the widely recognized priority of risk reductions, highest priority first. This is an iterative process between operator and suppliers. Steps of this iterative process include the following.

a) Elimination:

- 1) prohibit SIMOPS involving electrical work;
- 2) select completion equipment and procedures that may prevent unplanned motor rotation (see [5.4](#));
- 3) shorting and grounding of cable conductors at the point of working to reduce voltage potential (see [Section 14](#)).

b) Substitution:

Select electrical components that minimize the need to work on potentially energized conductors, for example:

- 1) noncontact instrumentation (see [Annex B](#));
- 2) nonhazardous voltage monitoring points on JB's (see [Annex B](#));
- 3) electrical cable feedthrough types (see [Section 14](#)).

c) Engineering controls:

- 1) grounding and isolation switches (see [Section 14](#) and [Annex D](#));
- 2) isolate/insulate the JB leads and perform LOTO;
- 3) use of lockable JB's with large terminal spacing;
- 4) distancing when working on energized equipment, such as remote readout;
- 5) use of continuous monitoring devices.

d) Awareness:

- 1) job safety briefing (see [Section 7](#));
- 2) task qualified personnel and specific required capabilities (see [Annex A](#));
- 3) any special operator and service supplier electrical safety program requirements;
- 4) access barriers (see [7.8](#));
- 5) signage (see [Annex E](#)).

e) Administrative controls:

- 1) risk assessment:
 - i. identifying the steps in a specific job being planned where the risks can occur;
 - ii. stating the mitigating action for all identified steps; this may result in a change of equipment selection;
 - iii. the risk assessment will form part of the job safety plan and be disseminated at the job safety briefing that is conducted by the responsible person on arrival at location (see [Section 7](#));
- 2) protocols in the event it is necessary to change operations during work, for example pumping down a well to maintain well control or a misrun during RIH that requires POOH due to a fault;
- 3) written procedures;
- 4) lone working policy (see [Section 7](#) and [Section 14](#));
- 5) permits to work, such as hot work permits to work in the hazardous area.

- f) PPE—Select PPE for protection against electrical shock and arc flash (see [Annex H](#)).
- g) Mitigation:
 - 1) develop first response plan;
 - 2) rapid egress and recovery of injured personnel;
 - 3) second person and emergency responder;
 - 4) availability of first aid trained personnel;
 - 5) sealing of cable in the BOP during well control event (see [12.2.2](#)).

[Annex K](#) shows some practical examples of equipment and techniques throughout this document as safety controls.

5.3 Job-specific Planning

Some topics are specific to job types. The relevant sections should be included in job safety planning, both for the main hazards and for outline workflows. These sections include:

- a) arrival at location (see [Section 7](#));
- b) RIH (see [Section 8](#));
- c) POOH (see [Section 9](#));
- d) commissioning (see [Section 10](#));
- e) surface electrical equipment (see [Section 13](#));
- f) maintenance (see [Section 11](#)).

The remainder of this job planning section covers selected safety aspects in detail.

5.4 Prevention of Unplanned Motor Rotation

5.4.1 General

This subsection provides recommendations and information intended to prevent or reduce the likelihood of unplanned motor rotation.

5.4.2 Simultaneous Operations

Warning—SIMOPS where electrical work is involved are a primary hazard.

Planning shall avoid the need for and prohibit SIMOPS.

SIMOPS such as pressure testing (hydrotesting) tubing, retrieving a wireline-set plug, operating a downhole valve, or raising or lowering tubing when performing electrical work can result in unplanned motor rotation and then electrical shock.

5.4.3 Well Kill

Normal well control practice is to use well kill fluid to prevent kicks. This will also reduce the likelihood of unplanned motor rotation.

5.4.4 Special Considerations Required for Live-well Installation and Retrieval

Live-well alternatively deployed systems require special attention between the operator, service supplier, and third-party companies. The well should be shut in sufficiently to seal around the deployment method with an applicable surface flow control device to maintain a pressure safety barrier. This will also reduce the likelihood of unplanned motor rotation. The operator should review carefully shorting, grounding, isolation, electrical and combustive risks, etc. when these systems are used.

5.4.5 Completion Tools

Prevention of unplanned motor rotation is a primary means of reducing risk.

Consider incorporating tools that prevent unplanned motor rotation, such as preventing fluid flow through the pump in either direction. Selection decisions will be made prior to a new installation (RIH), but use of such tools will then be required for POOH and maintenance.

Caution—Some deployment methods deploy the downhole motor and subsequently the pump. In such cases, unplanned motor rotation becomes a risk the moment the pump is connected to the downhole motor even though the topside is not connected. Similarly, surface PMM systems install the downhole pump and then mechanically link to the surface motor. See [Annex F](#).

While there are many different tools that can accomplish the same objective, it is recommended that they all should have the elements of 1) a removable flow-blocking device near the pump discharge to prevent fluid flow in either direction, 2) an operable communications port just above the flow-blocking device to enable draining of fluid from the tubing to annulus (or vice versa) without passing through the pump, and 3) a means of testing when used.

EXAMPLE A wireline retrievable plug located above the pump, and a compatible sliding sleeve set above the plug:

- The work procedure for RIH is then as follows.
 - a) Prior to makeup in the tubing string:
 - 1) test the plug and nipple in both directions;
 - 2) visually confirm that the sliding sleeve valve is open and the plug is in place.
 - b) Retrieve the plug and close the sliding sleeve only after the tubing hanger is landed, and the wellhead cable feedthrough and all surface electrical equipment connections are made. Closing the sleeve will normally be done during commissioning prior to startup.
- For other operations such as maintenance and POOH, the sleeve should be opened and a retrievable plug set. Testing may require fluid injection with sliding sleeve closed, to first pressure test the plug and then with the sliding sleeve open, to verify that pressure cannot be achieved.

This type of prevention of rotation is most applicable to RIH, POOH, and some types of planned maintenance.

Planning consideration shall be given to maintenance work or POOH when scale, wax, sand over the pump, or other issues prevent installation of the plug or operation of the sliding sleeve.

Freeing a stuck pump requires the prevention of rotation device to be disabled to pump fluid through it in either direction. The safety assessment should therefore include contingency mitigations; in this case, no electrical work (no SIMOPS).

Troubleshooting of a normally running system necessarily means prevention of rotation is inactive. Normal safe electrical practices shall be relied upon such as when making measurements.

Other equipment may be used to prevent rotation as part of the above three-step method, or it may be used separately after careful consideration of the nature of the well and as part of the overall safety plan. Such equipment may be also encountered during POOH or maintenance of PMM deployments that predate this document. Examples include the following.

- Use of a Y-tool with the bypass tubing blanking plug removed will provide a fluid bypass for the pump. In some cases, this can be combined with an isolation sleeve set across the pump discharge port into the Y-tool body thus eliminating the potential of fluid flow through the pump if the bypass tubing is plugged or restricted.
- Use of a tubing plug, for example for pressure test, or a packer, also prevents motor rotation. However, removal can result in unplanned motor rotation while the tubing and casing annulus fluid levels equalize. This shall be considered in the risk analysis and mitigating procedures.

Warning—This is an essential reason to require no SIMOPS: no electrical work while the fluid equalizes.

- Use of a deep-set safety valve raises similar considerations to the use of a tubing plug.
- Use of a self-acting check valve or diverter valve can prevent or reduce backspin but not forward spin from a well kick. These devices may be sufficient in a water well or when set below perforations.
- For POOH, perforation of the tubing to minimize fluid flow through the pump; this may not completely prevent rotation, and thus should only be considered as a last resort where the prevention of rotation equipment was not installed, has failed, or cannot be repaired or replaced.

PCPs (see [Annex F](#) and [Annex G](#)) typically require instant protection against over-speed damage, including stopping for any reason during normal operation. Devices that require manual intervention, such as operating a sliding sleeve valve in the example above, are not suitable for this purpose. A PCP has a breakout torque that prevents rotation until sufficient pressure difference across the pump is reached.

Warning—After a prolonged period supporting a fluid column, the PCP may unexpectedly commence unplanned motor rotation.

5.4.6 Mechanical Devices

Consider the use of testable mechanical devices that physically lock the motor or pump shaft and prevent rotation if/when they become available.

5.4.7 Pressure Equalization

After any valves are operated, or the BHA is moved up or down, time should be allowed for fluid levels to equalize in tubing and casing. Considerations to ensure fluid equalization include the following.

- a) It is recommended to monitor the cable end for any rotation to cease. (This may not be possible in POOH of a damaged electrical system.)
- b) Arbitrary waiting periods of 15 minutes or more are not recommended without justification. Estimation of the time needed for pressure to equalize considering depth, tubing diameter, and other characteristics of the installation and reservoir may be possible and should err on the side of caution.
- c) Regardless of waiting time or monitoring for pressure equalization, it is possible for a well to kick at any subsequent time.

If possible, it is recommended to use continuous monitoring of current or EMF to detect unplanned motor rotation, both when waiting for equalization to complete and in case rotation subsequently restarts.

5.4.8 Trip Speed

Too high an RIH/POOH speed can result in unplanned motor rotation from fluid flow through the pump.

When no provision is made to prevent fluid flow through the pump during RIH or POOH, then evaluate trip speed as a method of controlling flow through the pump that may result in rotation of the pump and motor. The service supplier may be able to help with determining a safe trip speed.

Continuous monitoring for unplanned motor rotation (see 5.6) can provide an adaptable compromise between overcautious slow trip speed and going too fast.

5.4.9 Motor at Surface

PMMs normally exhibit significant cogging torque, preventing free rotation of the motor shaft. There is normally no risk in making up or dismantling the BHA while the pump intake is above the wellhead, as any rotation that is caused will be slow and momentary.

The motor supplier should advise if the motor has low cogging torque that would allow potentially hazardous voltage to appear during handling and provide safe procedures. The supplier may provide a shaft anti-rotation device, possibly as part of a motor cap.

5.5 Protection of Personnel and Equipment

Protection of workers from electrical hazards is required by national and local regulations.

This section provides information to assist in protection of electrical workers regardless of the use of prevention of rotation devices.

A plan to rescue injured personnel from a confined space should be documented in the job safety plan and discussed in the job safety briefing.

It is recommended that at the location where work on exposed conductors is required, such as at the spooler, during a splice or during penetrator assembly, the cable conductors be shorted and grounded to form a local equipotential bonding zone. By eliminating voltage differences at the point of working, the risk of electrical shock will be greatly reduced. See [Section 14](#) and [Annex D](#) for further information.

5.6 Continuous Monitoring

5.6.1 General

Monitoring should be performed to protect from electrical risk and sparks around flammable gasses. Intermittent contact with exposed energized conductors, with enough energy, can create sparks and ignite a flammable mixture of gases. The use of flammable gas detectors and low explosive limit monitors are recommended where applicable.

EXAMPLE 1 Monitoring during the makeup of penetrators (see [Section 14](#)).

EXAMPLE 2 Monitoring for a low explosive limit condition or working with Megger insulation resistance tools.

EXAMPLE 3 Monitoring when cable splices cannot be made outside the hazardous area.

5.6.2 Gases

In order for combustion to occur, the triad of fuel, oxygen, and a heat/ignition source shall be present. If any one of the three is removed, then combustion will not occur. Before any electrical work activity near the wellhead is performed, well control should be performed to remove the fuel source (gas) from the triad.

5.6.3 Electrical

The use of a cable monitoring device that continuously monitors and alarms when voltage and/or current is present is recommended as it would alert the work crew to unplanned motor shaft rotation. Electrical work should cease immediately, and the cause of rotation determined if unplanned rotation occurs. The use of a cable monitoring (alarm) device has added benefit that actions can be taken to remove the potential ignition source (voltage) of the triad should there be escaping gas in low explosive limits.

5.7 Working with Electrical Cables and Penetrators

Recommended cable handling procedures apply to all phases of well operations—RIH, POOH, commissioning, well control events, and maintenance/troubleshooting.

Assessment of the risks of shock or arc flash during electrical working on potentially energized conductors should be performed. This is a normal requirement of national and local regulations.

Electrical cable feedthrough selection needs consideration if the work procedure requires makeup or disassembly at the wellhead, both for safe electrical working and because of the risk of sparks in the hazardous area.

Penetrators that do not create sparks when connected or disconnected, such as explosion-proof types, should be considered if flammable gases may be present at the wellhead.

See [6.2](#) for recommendations on cable preparation before deployment to the wellsite.

See [Section 14](#) for detailed guidance on all cable-related operations, including penetrators.

See [Annex D](#) for information on grounding for PMM operations.

See [Annex C](#) for detailed guidance on PPE.

See [Annex B](#) for detailed guidance on instrumentation and methods of measurement.

See [Annex H](#) for detailed guidance on arc flash assessment of PMMs.

5.8 Workspace and Safe Egress

The job safety plan should always address and provide adequate workspace with safe egress. When the wellhead and penetrator system is in a confined space, provisions should be made to monitor for the presence of flammable gas during makeup of the field penetrator system. The risk of shock or burn is compounded by the risk of arc, fire, or explosion if flammable gases are present.

A plan for first response to remove injured personnel from the confined space should be documented in the job safety plan and discussed in the job safety briefing prior to commencement of work at the wellhead location.

NOTE It is recommended at the well planning stage to consider placing the wellhead above ground level. If a cellar is required, ensure that it is large enough to allow rapid movement away from electrical hazards and allow safe egress and rescue.

5.9 Junction Boxes

A JB in the nonhazardous area wired to the wellhead electrical cable feedthrough is common to both PMM and IM systems (see [Section 13](#)). The following recommendations also apply to any electrical connection enclosure that may need to be accessed.

- The JB should be large enough to allow for safe making and breaking of connections, as well as electrical checks.
- The JB should be lockable so that it can be used with LOTO procedures.
- Terminations that allow for minimal conductor contact for removal are preferred.
- Consider incorporating nonhazardous voltage monitoring connections for ESP power cable voltage and/or current.

These recommendations apply to both PMM and IM installations.

5.10 Surface Equipment

Typical surface equipment and considerations are detailed in [Section 13](#). The selection and layout of this equipment should be such as to ensure it is clear which piece of surface equipment goes with the given BHA (especially important on multi-wellsites). The timing and details of the installation of this equipment needs to be identified and planned for up front as this may not necessarily coincide with BHA installation.

It is recommended that any surface cables run to the JB not be connected to the JB but rather have the ends protected against incidental contact and located inside the JB. Connection to the JB should occur during the steps outlined in commissioning (see [Section 10](#)). If the JB is not available on location, the cable ends should be shorted to each other or insulated and placed in a secured LOTO isolation device.

5.11 Isolation Switch

An isolation and/or grounding switch should be considered between the drive and the JB or integrated within them.

This will facilitate troubleshooting and maintenance of surface equipment by isolating and/or grounding the motor without accessing potentially energized conductors.

6 Equipment Preparation and Handling

6.1 General

Equipment preparation and handling is addressed when working with PMMs in the workshop or facility both prior to location shipment and upon return for inspection, repair, dismantle inspection failure analysis (DIFA) etc. Ensure that all paperwork clearly identifies the motor as a PMM.

6.2 Cable

It is recommended that the cable reel be delivered to the field with as much preparation completed in the workshop as possible in order to reduce cable handling and time in the field. This preparation may include:

- a) MLE to main cable splice;
- b) cable transposition splices;
- c) cable repair/extension splices;
- d) provision of a clean electrical bonding point on the reel;
- e) reel end of the cable, armor, jackets, insulation removed and prepared to allow electrical and gauge function checks during RIH;
- f) sufficient length of cable stowed in the reel center, such as 3 ft (1 m), to enable the phase conductors shorted together or insulated according to the intended safety practice and equipment to be used;

- g) fixing labels on the reel that identify it as to be used in a PMM installation; the labels should be visible at any rotary position of the reel in the spooler:
 - the labels should be removed before the reel is reused, unless for another PMM installation.

6.3 Motor Markings

PMMs should be marked distinctively from non-PMM and labelled as PMM. In the event of a third-party coating and delivery to wellsite, the coating company should mark the motor housing as PMM after the coating is applied.

6.4 Handling of Magnetic Devices

PMMs, once assembled, pose no special risks due to magnetic fields as the stator surrounding the rotor magnets acts as a magnet keeper that confines the fields to within the motor.

During motor manufacture and disassembly, there are hazards that the supplier addresses.

- a) Damage to personal effects caused by magnetic fields:
 - 1) medical devices, such as pacemakers;
 - 2) traditional watches and other magnetizable items.
- b) Large forces between rotors and between rotors and nearby steel parts; the forces increase rapidly as distance reduces and are generally uncontrollable by hand or improper tooling.
- c) Personal injury can result, especially crushed fingers when trapped by impact.
- d) Rotors may be damaged.

Special nonmagnetic equipment is used for controlled assembly and dismantling, including rotor insertion without damage into the stator.

Disassembly for a DIFA is normally conducted by the supplier. Where an intermediary or operator attempts disassembly from familiarity only with IMs, the above hazards apply and personnel injury and/or damage to the motor may result or be worsened.

6.5 Magnet Transport

Motor rotors and loose magnetized material require special packaging and markings to ensure awareness of hazard and reduce stray magnetic flux that may affect personal effects and other packages.

Completed motors do not normally require special packaging other than the steel shipping box, for ground and sea transport.

6.6 Air Transport

The International Air Transport Association considers magnets to be dangerous goods. It imposes a limit for the magnetic flux external to the packaging, which shall be verified by measurement. This is to eliminate the possibility of navigational errors caused by magnetic influence on compasses.

Verification applies to motors and magnetic motor components.

6.7 Disposal

Magnetic material should be recycled or disposed of according to any regulations that apply. In damaged motors, magnetic material may be found throughout the interior of the motor.

7 Arrival at Location

7.1 General

This section covers initial actions in all circumstances in which personnel and equipment arrive at the wellsite for PMM-related work. It is referenced as the first steps to follow in each of the RIH, POOH, commissioning, and troubleshooting and maintenance sections.

In accordance with normal industry practice, any person arriving at the wellsite should first report to the responsible person. If PMMs are or will be in use at the wellsite, the responsible person will:

- a) instruct anyone not involved in relevant well operations that PMMs are in use, give a brief explanation of the hazards involved, and direct where the person may and may not go;
- b) instruct anyone who will be involved in well operations to attend the job safety briefing.

7.2 Job Safety Briefing

The job safety briefing shall be held before service vehicles and service equipment are positioned and personnel commence work activities. The objective of the job safety briefing is to ensure all personnel are aware of the potential risks of working with PMM systems and understand the tools, instrumentation, equipment, and processes to keep everyone safe for the job to be undertaken. The job safety briefing is the last formal chance, before any stop work authority is taken, to address any change that may have occurred between the job safety planning and the job safety briefing. The briefing will cover the entire scope of the job in addition to the following PMM-specific topics. In no priority of order, these topics include the following.

- a) Identify all hazards and risks involved, for example:
 - 1) site conditions;
 - 2) electrical shock;
 - 3) arc flash;
 - 4) hot work;
 - 5) combustion triad—fuel, oxygen, heat/ignition source:
 - i. control the gases;
 - ii. control the energized condition that leads to creation of sparks.
- b) Discuss the electrical hazards and risks created by introducing unplanned motor rotation with fluid movement through the pump.
- c) Review wellsite preparation, equipment spotting, and grounding of equipment to the approved grounding point location, which is typically but not always the wellhead.
- d) Review access barriers that will provide a limited access work area where cable operations, including cutting, splicing, and electrical cable feedthrough makeup, are to be performed.
- e) Establish who will be qualified to cross the access barriers and what the safety requirements are within the identified approach boundaries.
- f) Identify the personnel who are task qualified to be on location and work on a PMM.
- g) Specific equipment and mitigations to be used for the job should be reviewed.