

# **Permanent Magnet Motor Safety**

**API RECOMMENDED PRACTICE 11S9**

**FIRST EDITION, XXXXXXXXXXXX, 202X**

BALLOT DRAFT

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## Introduction

In electric 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.

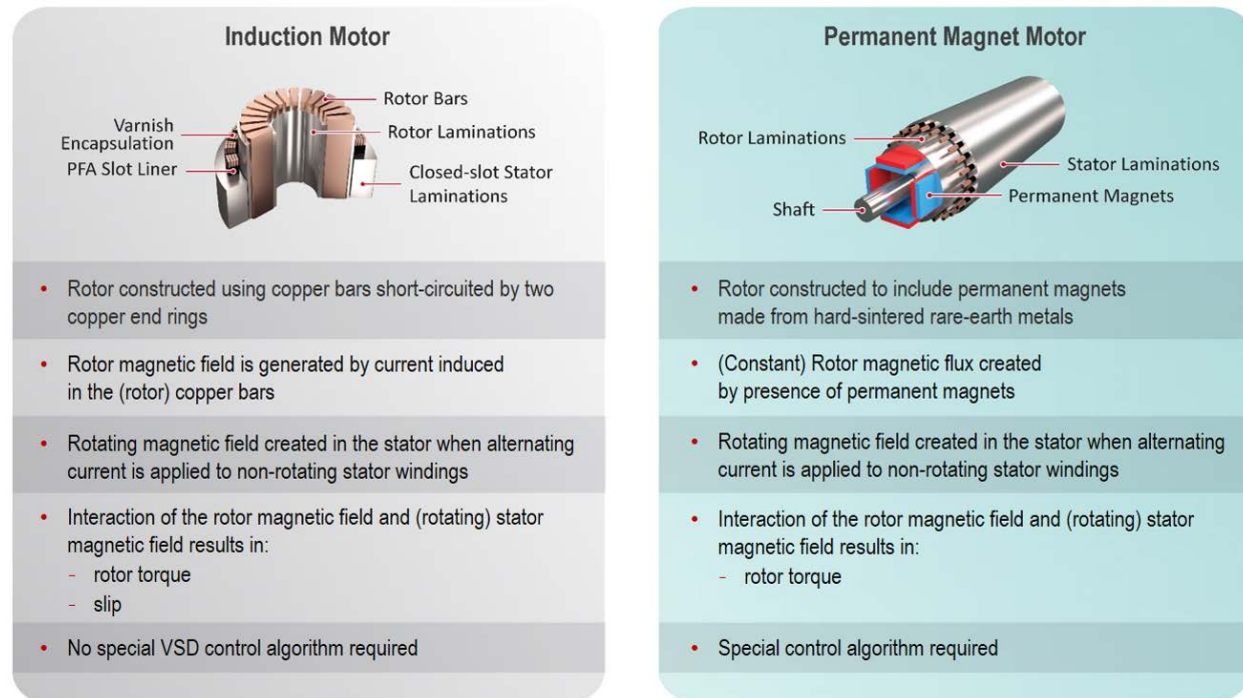


Figure 1—Comparison of induction and permanent magnet motors

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.
- While 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.

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One of the implications of this is that the PMM will typically have a much lower idle current than the IM. While 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 which can lead to various electrical hazards, shock, burns, or arc flash.

Despite the EMF associated with PMM technology, their benefits in energy and CO<sub>2</sub> 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.

## 1 Scope

This document serves to emphasize safety aspects and recommended practices concerning the handling, installation, trouble shooting, operation and pulling of 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 electric submersible pump (ESP). A progressing cavity pump mated with a downhole motor with or without a gear reduction unit is typically called an electrical submersible progressing cavity pump (ESPCP).

For this recommended practice Figure 2 will be used as reference for a high voltage conventional electrical submersible pump 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 afore mentioned 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 coil tubing with external cable	8.7	9.16	F.5
Through tubing coil 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 while 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 permanent magnet motor 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 permanent magnet motor 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.

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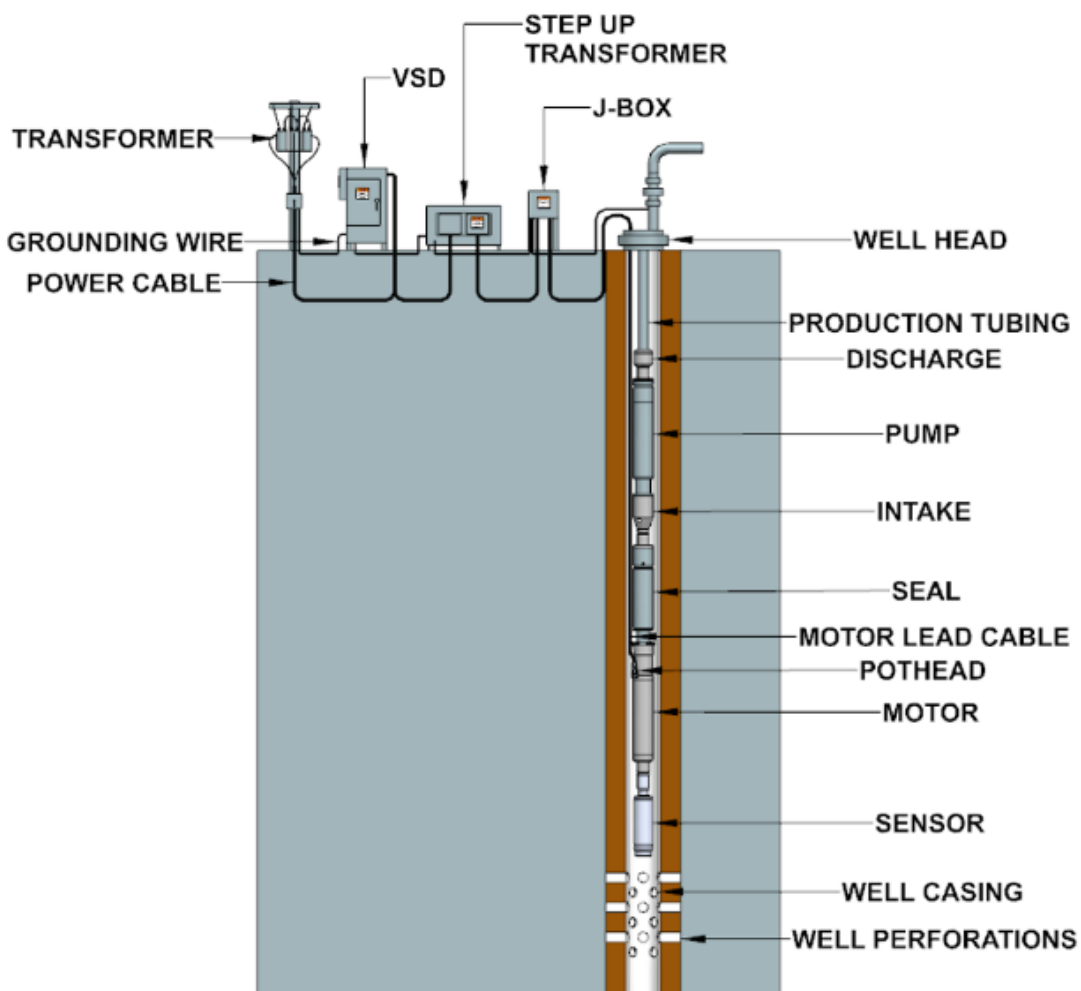


Figure 2—Typical high voltage ESP system.

After an introductory review of the nature of risks potentially arising from the use of PMMs (section 4), 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.

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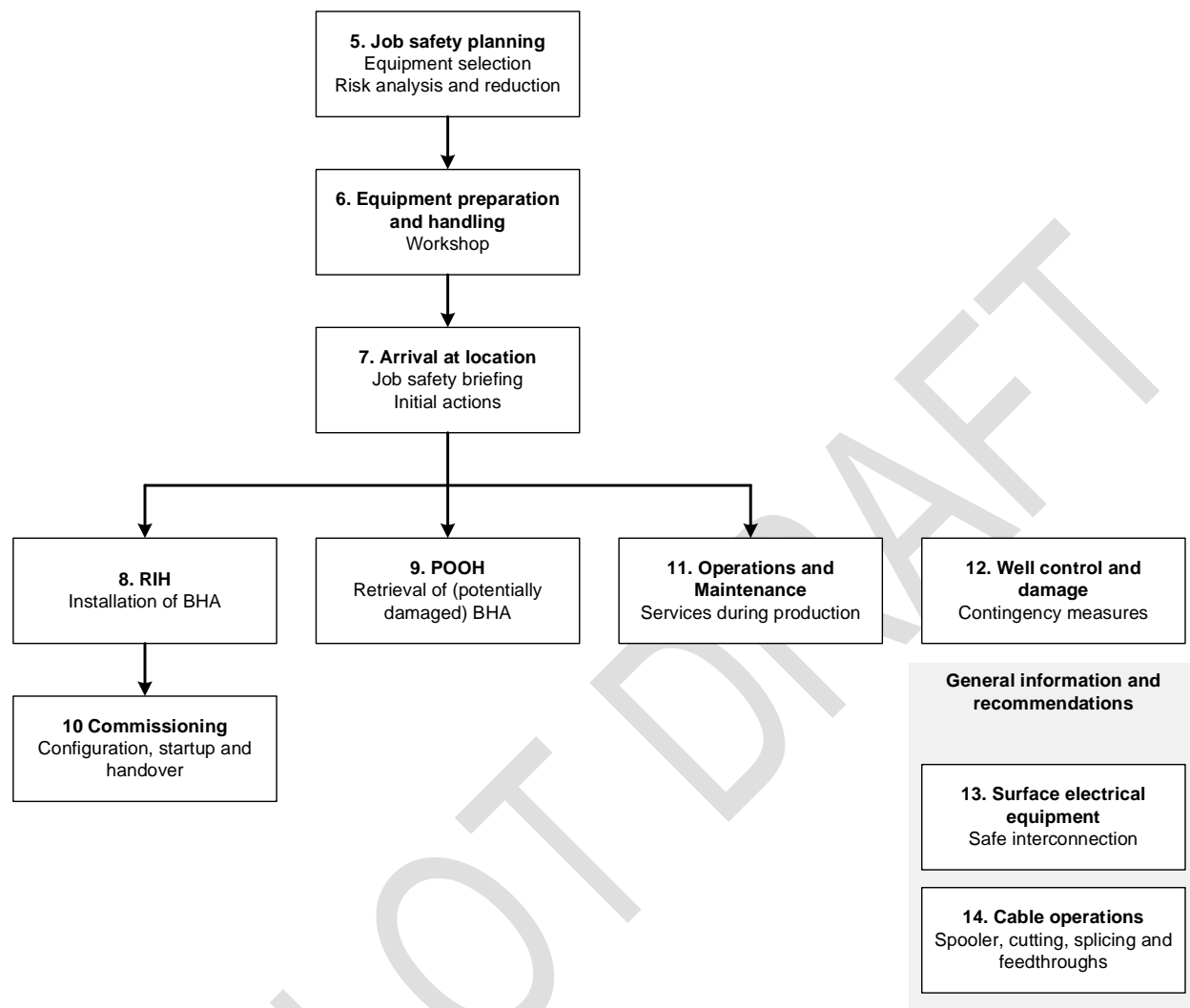


Figure 3—Operational flow of document.

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

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

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

IEC<sup>1</sup> 60079-0, *Explosive atmospheres – Part 0: Equipment, General requirements*

IATA<sup>2</sup> *Dangerous Goods Regulations (DGR)*

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<sup>1</sup> International Electrotechnical Commission, 3 rue de Varembé, PO Box 131, CH-1211 Geneva 20, Switzerland

<sup>2</sup> International Air Transport Association, 33, Route de l'Aéroport, PO Box 416, 1215 Geneva - 15 Airport, Switzerland

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### **3 Terms, definitions, symbols, and abbreviations**

#### **3.1 Terms and Definitions**

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

##### **3.1.1**

##### **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 well head

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

##### **3.1.2**

##### **arc flash**

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

##### **3.1.3**

##### **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  $1.2 \text{ cal/cm}^2$  [ $5 \text{ J/cm}^2$ ]

NOTE See also thermal burns and Annex H for detailed discussion.

##### **3.1.4**

##### **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 RP 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) blow out preventer serves as the two barriers. Some of these same devices/methods may be used as flow control which is critical to limit unplanned motor rotation (see section 5.4).

##### **3.1.5**

##### **back spin**

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

##### **3.1.6**

##### **bottom hole assembly**

**BHA**

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the electric submersible pumping equipment deployed into the well, principally comprising pump, motor seal, motor and sensors

### **3.1.7**

#### **braided line**

a multi-strand wire rope, typically steel, that 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 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 stages. Centrifugal pumps will act as hydraulic motors (turbines) when fluid is pumped through them, such as during back spin.

### **3.1.12**

#### **cogging torque**

detent torque

an internal force between the magnets of the rotor and the stator laminations pulling the shaft of an un-energized motor to any of a number of a stable positions

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

### **3.1.13**

#### **coiled tubing**

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

### **3.1.14**

#### **commissioning**

the phase of work between installation of the ESP in the well during RIH and handover to the operator after satisfactory start-up pumping.

### **3.1.15**

#### **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.



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**EXAMPLES** 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.

### **3.1.16 conduit box**

electrical supply conduit outlet body with a gasket cover

**NOTE** In the USA 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 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 system**

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

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

### **3.1.21 electric line**

e-line

a multi-strand wire rope, typically steel, formed around one or more insulated electrical conductors, that is stored on a winch unit and is used to deploy electrical equipment into a well bore and operate it

### **3.1.22 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 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) and motor designs (PMM, Linear Induction Motor (LIM), and Linear Synchronous Motor (LSM)). Because vendors loosely call any pump downhole driven by an electric 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.

### **3.1.23 ESP power cable ESP cable**

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three phase electrical cable, including the MLE, running from the motor terminals through the well head 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 non-metal (polyfluoroalkyl or other polymer material).

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

### **3.1.24**

#### **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.

### **3.1.25**

#### **energized conductor**

live conductor

a cable conductor that is carrying voltage and/or current

### **3.1.26**

#### **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.

### **3.1.27**

#### **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

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#### **3.1.31**

##### **hazard**

a source of possible harm, and more particularly electric shock, sparks, or arc flash

#### **3.1.32**

##### **hazardous voltage**

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

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

#### **3.1.33**

##### **hazardous area**

classified area

an area, typically encompassing the well head, in which flammable vapor is often present, and which may be ignited by an electric spark, resulting in fire and/or explosion

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

#### **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 electric motor in which the rotor magnetic field is induced from the stator magnetic field created by the stator magnetizing current.

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

#### **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 well-site given by the responsible person to all relevant personnel prior to commencement of work

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

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**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 electric 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 section 14.3.

**3.1.43**

**lock-out tag-out**

**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

EXAMPLES 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 permanent magnet motor 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

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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 electric 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

EXAMPLES 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 Induction motors are commonly two poles while permanent magnet motors 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 electric 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.

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**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:

- 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 bottom hole assembly into the well bore

**3.1.61**

**shock hazard**

possibly harmful effects of an electric 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 which 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, that 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**

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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 variable speed drive, which raises the drive voltage to the voltage required to operate the downhole motor

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

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 system. Systems that do not use a step-up transformer sometimes use an isolation transformer at the input to the variable speed drive. 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 (OEM), 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.

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#### **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 which results in the motor acting as an electrical generator

#### **3.1.75**

##### **variable speed drive**

##### **VSD**

variable frequency drive (VFD)

adjustable speed drive (ASD)

adjustable frequency drive (AFD)

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 non-hazardous 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 which may migrate up the ESP power cable and onwards 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 well head feedthroughs block all gas migration, and the JB is not required to be vented.

#### **3.1.77**

##### **well kick**

an unpredictable and generally 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 run in hole (RIH) and POOH to prevent or control well kicks

#### **3.1.79**

##### **wireline**

slick line, braided line, or electric line according to context

### **3.2 Symbols and abbreviated terms**

AC	alternating current
AWG	American wire gauge
BHA	bottom hole assembly



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BOP	blow out preventer
CT	coiled tubing
DC	direct current
DIFA	dismantle inspection failure analysis
EMF	electromotive force
ESP	electrical submersible pump
HMI	human-machine interface
IATA	International Air Transport Association
IM	induction motor
IT	isolated terre (French ground/earth)
JB	junction box
JSA	job safety analysis
LOTO	lock out, tag out
MLE	Motor lead extension
NFPA	national fire prevention association (USA)
OEM	original equipment manufacturer
PCP	progressing cavity pump
PMM	permanent magnet motor
PMM-ESP	permanent magnet motor electrical submersible pump
POOH	pull/pulling out of hole
PPE	personal protective equipment
RIH	run/running in hole
RRP	reciprocating rod pump
SI	International System of Units
SIMOPS	simultaneous operations
SRP	sucker rod pump
TDR	time domain reflectometer
TEC	tubing encapsulated cable
VSD	variable speed drive
rpm	revolutions per minute
$\Omega$	ohm, SI derived unit of electrical resistance
Hz	hertz, SI derived unit of frequency

## 4 Nature of Risks and Approach to Safety

### 4.1 Multiple Sources of Power

In a traditional ESP application, the power source is usually only considered to be from the utility or generator. However, in a PMM application (as outlined in the introduction), in addition to the line power the PMM will generate internal voltage known as electromotive force (EMF) when externally forced to rotate, regardless of direction. Causes of this forced rotation of the shaft can include an ESP pump acting as a turbine or a PCP acting as a hydraulic motor. When this rotation occurs, any connected surface equipment will become energized even if disconnected from the utility power. The amount of voltage produced is generally 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.

This change from one primary electrical power source to potentially two electrical power sources is 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 RP.

Any contact with electrical energy can cause severe harm to personnel. This may include electric 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 generally considered hazardous. The sensation of electric shock typically may occur at low current, for example 5mA. 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 which 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 110V 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 which provides a degree of safety in case of incidental contact with the 110V conductor.

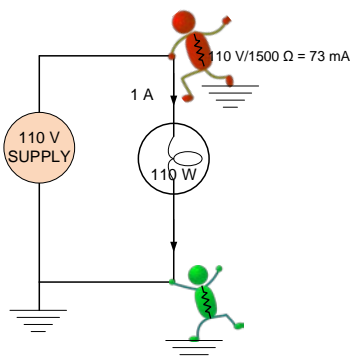


Figure 4—Voltage and current in electric shock.

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**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.

## **4.2 Unplanned motor rotation**

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

- a) Run in hole (RIH) (fluid direction is pump intake to pump discharge)
- b) Pull out of hole (POOH) (fluid direction is pump discharge to pump intake)
- c) Well kick (fluid direction is pump intake to pump discharge)
- d) Back flow after the system is shut down (fluid direction is pump discharge to pump intake)
- e) Fluid injection (injection through the annular space would generally cause fluid to move through the pump intake to the pump discharge while injection through the tubing would cause fluid to move from the pump discharge to the pump intake)

These causes result in back spin 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 non-hazardous.

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 multi-tiered approach rather than only one method of protection. See sections 4.3, 4.4 and 5 for a more detailed evaluation of these tiers.

In an installed system back spin 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 which 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 back spin in an unpredictable manner. PCPs can back spin fast enough to destroy the stator elastomer and exceed VSD ratings unless preventative measures are taken.

### **4.2.1 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 section 5.4 for examples and further details.

### **4.3 Electrical protection**

#### **4.3.1 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. Utilizing surface equipment with lockable enclosures and performing associated 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 SIMOPS.

#### **4.3.2 Open and closed ESP 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 un-grounded 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.

### **4.4 Risk management**

Risk management in this document is based on:

- a) Assessment during job safety planning (section 5):

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- 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 (section 6) to minimize wellsite risks.
- e) Safety briefing upon any arrival of personnel on location (section 7).
- f) Protection of electrical workers by recommended practices, primarily in cable operations and measurements (sections 14, 14.8.4 Annex B), PPE (Annex C) and requiring task qualification (Annex A).
- g) Ensuring signage (Annex E) informs personnel of hazards.
- h) Utilizing properly rated and applicable PPE, test instruments, and tools for the task (Annex B and Annex C).
- i) Performing lock out tag out (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 H<sub>2</sub>S 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 sub-sections.

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 but others. Others, such as troubleshooting of an existing system, may have only a few safety aspects to consider.

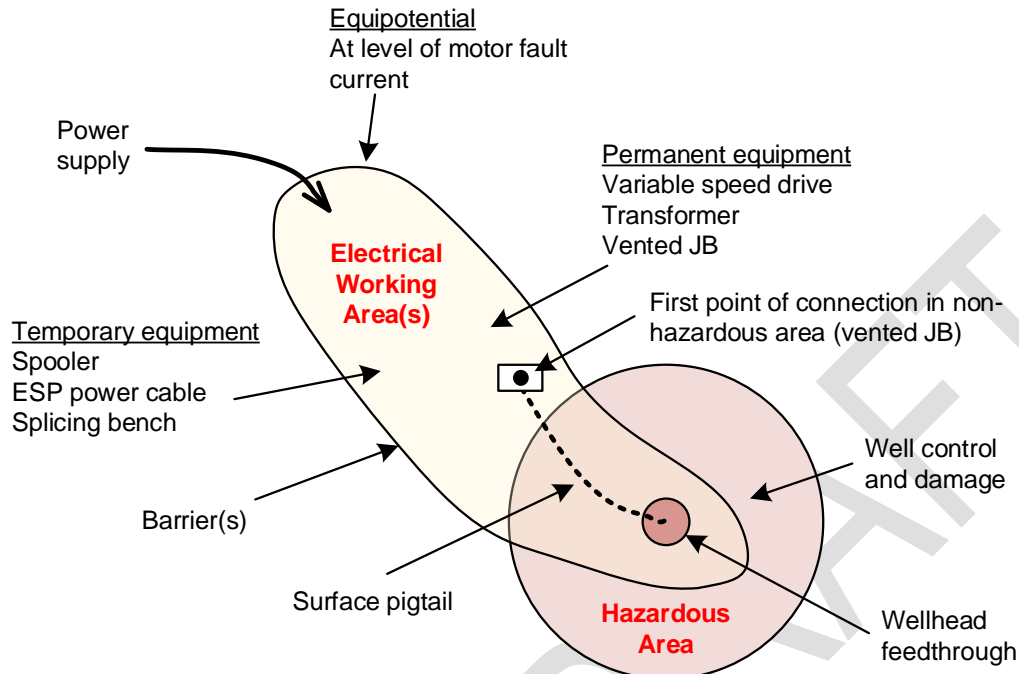


Figure 5—Hazardous and Non-hazardous areas at wellsite location.

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 well head and continues as a surface pigtail into a non-hazardous 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:

- Description of the overall job, equipment selection and the individual tasks needed.
- The risks associated with unplanned motor rotation and methods of prevention.
- Well control (section 12).
- Identification of electrical hazards associated for each task.
- Shock assessment for tasks involving a shock hazard.
- 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.
- Spark assessment - creating sparks in a hazardous area where flammable gases are present

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- 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:

- a) Elimination
  - 1) Prohibit simultaneous operations (SIMOPS) involving electrical work.
  - 2) Select completion equipment and procedures that may prevent unplanned motor rotation (section 5.4).
  - 3) Shorting and grounding of cable conductors at the point of working to reduce voltage potential (section 14).
- b) Substitution
  - 1) Select electrical components that minimize the need to work on potentially energized conductors, for example:
  - 2) Non-contact instrumentation (see Annex B).
  - 3) Non-hazardous voltage monitoring points on JBs (see Annex B).
  - 4) Electrical cable feedthrough types (see section 14).
- c) Engineering controls
  - 1) Grounding and isolation switches (see section 14 and Annex D).
  - 2) Lockable JBs with large terminal spacing.
  - 3) Distancing when working on energized equipment, such as remote read-out.
  - 4) 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 section 7.8).
  - 5) Signage (see section 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.



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- 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 sections 7 and 14).
- 5) Permits to work, such as hot work permits to work in the hazardous area.
- f) PPE
  - 1) Select PPE for protection against electric shock and arc flash (see Annex G and Annex H).
- g) Mitigation
  - 1) Rapid egress and recovery of injured personnel.
  - 2) Second person and emergency responder.
  - 3) Availability of first aid trained personnel.
  - 4) Sealing of cable in the blow out preventer (BOP) during well control event (see section f)).

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 (section 7).
- b) RIH (section 8).
- c) POOH (section 9).
- d) Commissioning (section 10).
- e) Surface electrical equipment (section 13).
- f) Maintenance (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 sub-section provides recommendations and information intended to prevent or reduce the likelihood of unplanned motor rotation.

#### **5.4.2 Simultaneous operations (SIMOPS)**

**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 electric shock.

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#### **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 utilized.

#### **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.8.

While there are many different tools which 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 sliding sleeve set above the plug:

- The work procedure for RIH is then:
  - Prior to makeup in the tubing string:
    - Test the plug and nipple in both directions.
    - Visually confirm the sliding sleeve valve is open and the plug is in place.
  - Retrieve the plug and close the sliding sleeve only after the tubing hanger is landed, and the well head cable feedthrough and all surface electrical equipment connections are made. Closing the sleeve will normally be done during commissioning prior to start-up.
- For other operations like 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).

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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:

- 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 prevents back spin, but not forward spin from a well kick. This may be sufficient in a water well or when set below perforations.
- Use of a self-acting (automatic) diverter valve above the pump discharge can prevent or reduce backspin, but not forward spin from a well kick. This 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 (sections F.8 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 which 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:

- 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.

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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 section 5.6) can provide an adaptable compromise between over-cautious 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 electric 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 LEL monitors are recommended where applicable.

EXAMPLE 1 Monitoring during the makeup of penetrators (see section 14).

EXAMPLE 2 Monitoring for a low explosive limit (LEL) condition or working with Megger IR tools.

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

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### **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 make-up or disassembly at the wellhead, both for safe electrical working and because of the risk of sparks in the hazardous area.

Penetrators which 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 section 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 it is large enough to allow rapid movement away from electrical hazards and allow safe egress and rescue.

## **5.9 Junction boxes**

A junction box (JB) in the non-hazardous area wired to the well-head 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 non-hazardous 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-well sites). 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 (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 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) Motor lead extension (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.
  - 1) The labels should be removed before the reel is re-used, 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 well site, 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 which 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 non-magnetic 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 induction motors, the above hazards apply and personnel injury and/or damage to the motor may result or be worsened.

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## **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**

IATA 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 as well as 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 well site 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 well site 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 that 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 which 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:

- a) Identify all hazards and risks involved, for example
  - 1) Site conditions,
  - 2) Electric shock,
  - 3) Arc flash,
  - 4) Hot work
  - 5) Combustion Triad: fuel, oxygen, heat/ignition source,
    - i. Control the gases
    - ii. Control the energized condition which 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 make-up 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.
- h) Review use of well-kill fluid and shut-in procedures for RIH and POOH. Confirm well kill fluid is in place.
- i) Review the emergency plan for well kicks or other unplanned events (see section 12).

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- j) Review work procedures to prevent any parallel (simultaneous) well site operations while installing, pulling, commissioning, or performing electrical connection activities or electrical checks (resistance and/or downhole sensor). This is two-way precaution for well crew and PMM technicians.
- k) Review operation of any prevention of rotation devices to be installed or which are already installed. If intervention is required for operation of the devices, emphasize the potential for accidental SIMOPS. Intervention and electrical work shall be coordinated and not simultaneous.
- l) Review LOTO plan and require verification of all related locations after the job safety meeting. Figure 6 shows typical locations for LOTO application. The incoming supply switch (far left) is the LOTO position normally used for all systems, IM and PMM. The remaining locations provide means for LOTO of EMF, for example, to work on the drive. See section 14 for additional information.
- m) Review PPE to be used. Confirm test certification is current for items such as insulating rubber gloves and hot sticks that require periodic inspection and recertification testing.
- n) Require visual inspection and any functional test of all PPE that will be utilized after the job safety meeting and verification that it is undamaged and safe to use.
- o) Meeting participants should review and acknowledge a job safety briefing form or checklist, after which the Responsible Person can authorize work to proceed.
- p) Some operators may authorize the work crew to exercise their stop work authority if any unsafe work practices are observed once work has started at the job location.

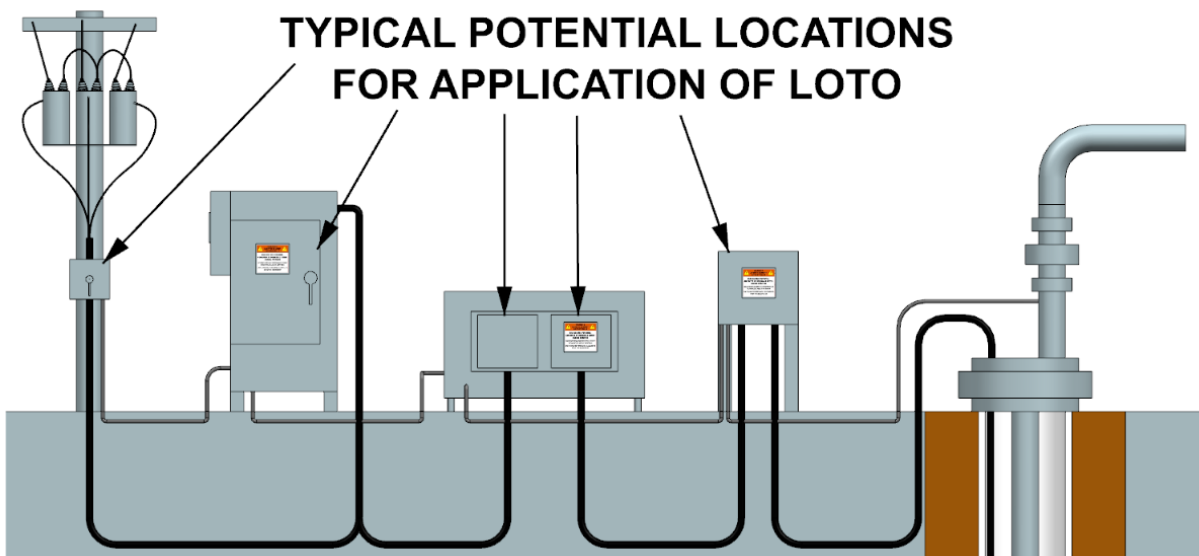


Figure 6—Possible locations for LOTO.

### 7.3 Arrivals during work

The responsible person should ensure that a late arrival is informed and directed as if a normal arrival participating in the job safety briefing.

The responsible person may require work to be stopped to allow the new arrival to set-up for work.

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A crew-change will necessitate a renewed job safety briefing to work continuation and job handover from the current crew.

#### **7.4 Unplanned call-out/troubleshooting**

It is recognized that task qualified persons may need to be called out at any time of day or night for troubleshooting, and that the wellsite may be unattended.

It is recommended that the dispatcher should advise the service technician if a PMM is installed in the well.

CAUTION—Personnel should always assume a PMM is installed until proven otherwise.

The responsible person and service supplier should review the hazards including any mitigation measures required to be implemented and should agree whether:

- a) One person may visit (for example to adjust or inspect equipment without opening it).
- b) A PMM isolation switch and/or safe monitoring points built into JBs may extend the range of work a lone person can safely perform.
- c) Two persons are recommended for electrical safety in accordance with section 14 (for example to troubleshoot by opening a JB and taking measurements).
- d) Larger attendance is required.

Operators and service suppliers may have lone-working policies and procedures.

See also section 14 for working on cables.

#### **7.5 Work Plan Execution Activities**

During activities preparatory to RIH the PMM is not yet connected and there are no PMM specific related electrical hazards.

This is not the case for POOH, commissioning and maintenance where the PMM is already installed and connected. (See section 9).

#### **7.6 Spooler (RIH and POOH)**

Position the spooler with a clear line of sight to the rig floor and rig floor operator.

Ensure the work area around the spooler is dry and clear of trip hazards.

If the site / platform layout does not allow the spooler operator a clear line of sight of the wellhead and rig floor, then a spotter who has direct communication with the spooler is required. This is especially critical during offshore operations when the spooler may be on a workboat or barge separate from the platform or rig. The spotter shall be in place any time a technician or spooler operator is inside the access barrier and performing electrical work.

See section 14 for subsequent cable operations and measurements.

#### **7.7 Grounding**

Establish grounding and bonding in accordance with national and local regulations, and operator-specific practice.

Grounding recommendations for PMM installations are given in Annex D.

Establish equipotential bonding between cable, spooler, and all rig structures according to section 14.

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For alternatively deployed systems which may not require a rig, the rigless equivalents (pressure control equipment, wireline unit, lubricator etc.) should be equipotential bonded.

## **7.8 Access Barriers and Alerting Techniques**

To prevent or limit access to the work areas, establish access barriers in conjunction with safety signage or other alerting means. For example, audible alarms or flashing beacons around the spooler unit, splicing area, wellhead and rig floor may be used to warn personnel of the work areas containing energized conductors or circuit parts.

Access barriers should be clearly visible and continuous with no interruption. One example is a plastic caution barricade tape that is red and black, yellow and black or other recognized color combination that identifies the area behind the tape as a restricted area.

In addition to the access barrier, or where the installation of one is not practical, a watch person may be designated to keep unauthorized personnel out of the work area.

The minimum recommended distance from potentially exposed energized conductors is 10 ft [3 m]. This distance may be adjusted to meet regulatory requirements or specific operator / service supplier internal safety requirements.

## **7.9 Surface Equipment**

Typical surface equipment details and considerations are outlined in section 13. Prior to beginning the steps outlined in RIH (section 8) or POOH (section 9), ensure that the surface cable from the JB to the transformer is disconnected at the JB and that the ends are protected from contact. In addition, the line power should be disconnected and LOTO performed.

## **8 Installation (RIH)**

### **8.1 General**

The scope of installing the downhole equipment per this section includes the general steps of assembling the BHA on or at surface, lowering the equipment into the well, assembling the wellhead, completing the wellhead cable feedthrough, and then providing the cable ends to the vented JB.

It is critical that all the steps outlined in section 7 be performed prior to beginning the actual equipment installation covered in this section. The installation of the PMM may be the first time that many individuals encounter this type of equipment.

Prior to installation, the risks associated with most PMMs are like those of IMs. The act of installing the equipment is typically the first process that brings on additional risks. (See section 4 on the nature of the risks and some potential mitigation methods).

Specific installation procedures will differ between equipment suppliers and the type of deployment, as there are many different considerations and situations that may occur.

### **8.2 RIH-specific job safety planning**

The following recommended practices should be discussed in the job safety plan (section 5).

#### **8.2.1 Misrun**

During RIH, there is potential for a downhole electrical short or other mishap and thus the need for retrieval of the ESP may occur. Should this occur, See section 9, POOH.

Procedures shall be in place for cutting cable in the event of BOP use due to a well event. See section 12, well control.

#### **8.2.2 Cable Electrical Checks**

Many of the practices for testing and verifying cable electrical integrity are common among the various methods of PMM deployment outlined in this document. These instructions should be reviewed as per section 6, job safety planning.

### **8.3 General RIH Actions**

#### **8.3.1 Eliminate or Reduce Downhole Fluid Movement**

##### **8.3.1.1 Prevention of rotation**

Review and install any method identified in the pre-job plan (per section 5) for preventing or minimizing rotation of the pump. See sections 8.5 through 8.10 for considerations of alternatively deployed systems.

##### **8.3.1.2 Trip speed**

Ensure the trip speed does not exceed that identified in the pre-job planning per section 5. For trip speed considerations see section 5.4.8.

#### **8.3.2 Cutting Cable in Preparation for Splicing and Penetrator**

Review and perform cable cutting operations as required per the job safety plan identified in section 5. Refer to section 14 on cable operations for various risk mitigation methods and detailed recommendations.

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### **8.3.3 Downhole packer penetrator**

During RIH where a downhole packer penetrator is to be installed, perform the make-up per the supplier procedures as explained in section 14.8. The cable-handling precautions in section 14.3 also apply.

### **8.3.4 Cable Electrical Checks**

Prior to beginning installation of the BHA, prepare the ESP power cable ends to eliminate any incidental contact with an exposed conductor. All three phases of the ESP power cable should be shorted together and grounded, or isolated as required in the cable reel. The decision to short the conductors together and ground, or electrically isolate will be based on the operator or equipment installer's established procedures and the given operation being performed. Refer to section 14 for additional considerations and risk mitigations.

If selected per the pre-job planning in section 5, install the continuous monitoring device per the equipment supplier's instructions.

Appropriate PPE shall always be worn while handling and verifying any aspect of a PMM electrical system. Additional information for applicable PPE for cable electrical checks can be found in Annex C.

Before performing electrical or functional checks on the cable or downhole gauge, no voltage and/or current shall be confirmed. Use the absence of EMF live – test – live method for confirmation to ensure the test device is working properly. Measurement should be performed phase to phase and phase to ground on all three phases. If any voltage and / or current is present, no work should be performed until the cause of the motor shaft rotation is mitigated. Instrumentation requirements for proving the cable is not energized prior to any personnel contact are outlined in Annex B.

### **8.3.5 Surface Wellhead Connections**

Confirm appropriate access barriers per section 7.8 have been established.

When the last joint of tubing has been installed and the last ESP power cable band has been placed, it is recommended to place a durable warning label next to the last band containing the wording, "Warning - PMM In Use". This warning label should be done by the ESP service provider and may be affixed by band, sticker or other means suited to the below wellhead environment which does not interfere with the operations of the well. This messaging is to remind work crews of the potential hazard if the PMM power cable is cut. See section 14.

When the surface cable or cable end is connected to the wellhead feedthrough in the hazardous area, the risk of shock and an arc from unplanned motor rotation, and ignition of flammable gas if it is present. See section 14 for detailed consideration.

Any completion components installed to prevent fluid flow through the pump should be configured to block fluid flow through the pump. The back-pressure valve should not be retrieved until the penetrator connector is attached. If no back-pressure valve is installed, then the master, wing or flow line valve(s) should be closed. The completion component should be tested once the device is activated or set in place.

Confirm that the conductors at the free end of the cable (that will be terminated at the JB or other surface location) are electrically insulated to prevent any contact with the conductors. The free end of the cable should be physically protected and marked to warn personnel from contacting it.

Prior to making the connection of the surface cable to surface side of the penetrator, perform both phase to phase resistance and phase to ground insulation testing of the surface cable to verify the integrity of the system.

Using the appropriate PPE as outlined in Annex C to mitigate the risk of shock or arc flash, check the outside of the penetrator for EMF with a suitable non-contact voltage detector as per Annex B. If no EMF was detected, proceed to remove any penetrator protective cover, and check for EMF on the conductor

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with a suitable voltage detector. If no EMF is present, the surface cable connector may be connected to the wellhead penetrator. See section 14.8 for further details.

## 8.4 Conventionally Deployed

The following is an outline of the general RIH steps for conventionally deployed PMM-ESP systems, following the flow shown in Figure 7.

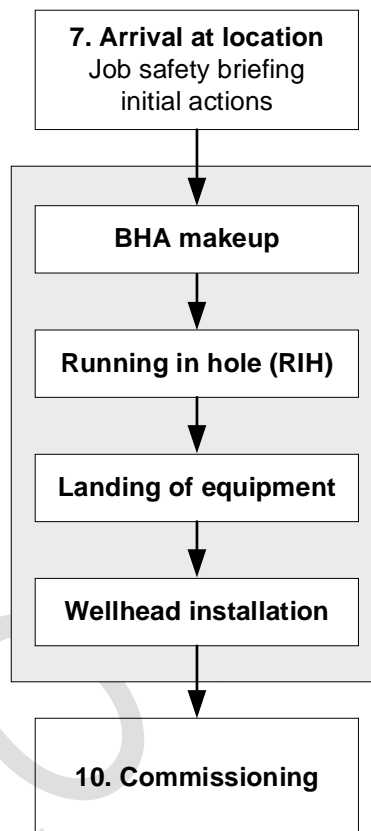


Figure 7—RIH workflow.

Specific hazards and mitigations for PMMs are considered in each step. However, not every specific step of an installation may be included, particularly if not introducing new hazards specific to PMMs. Safety considerations that are more general and not PMM specific may not be included in this RP.

**WARNING**—Ensure all personnel are aware of the equipment being installed and the associated hazards. Ensure the job safety briefing is performed per section 7.

**NOTE** Each equipment supplier will have specific procedures for the equipment being provided. Some situations may require site specific instructions. In this case, the procedures are to be developed with collaboration between the equipment supplier and the operator.

The appropriate PPE is to be selected and be worn for each applicable operation per Annex C.

### 8.4.1 Arrival at Location

The following workflow follows Figure 7.

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- a) Verify lock-out, tag-out (LOTO) is in place (and perform if not in place) at the surface power source (such as at utility pole), VSD, and vented JB as applicable.
- b) Rig up with appropriate grounding of the rig and any surface equipment per Annex D.
- c) Implement well control methods as applicable (such as pumping kill fluid, installing a BOP, etc.). Refer to section 12 for further details.
- d) Locate the cable spool with access barriers, apply appropriate grounding per section 7.

#### **8.4.2 BHA makeup**

Typical steps of the BHA makeup will include:

- e) Prepare cable ends per equipment supplier specifications.
  - 1) This may include steps such as shorting and grounding, isolating, and insulating the exposed ends of the leads, or installing an engineered cable monitoring box as applicable.
  - 2) Regardless of the methods used, the ends of the cable should be prepared against incidental contact.
- f) Connection of ESP components (such as sensor, motor, seals, intake, pump, etc.)
  - 1) When the pump intake is above the wellhead, the only rotation of the rotor string will be planned rotation as required for typical equipment mechanical checks and determining direction of rotation. There are no electrical hazards from rotation.
  - 2) Install any prevention of rotation devices identified in the job safety plan, and as reviewed in the job safety briefing, for mitigating the risks associated with downhole fluid movement. The equipment should be tested once it is activated or set in place as applicable.

#### **8.4.3 Running in Hole**

**WARNING**—If any voltage or current is present at any point in the process, do not continue with any electrical integrity check (or any other part of the equipment installation) until the voltage or current is no longer present. As applicable, take action to mitigate any cause of unplanned equipment rotation to eliminate the voltage generation and/or current flow in the cable. These mitigation steps may include:

- g) Verify the electrical system integrity and downhole sensor with checks at intervals defined by the equipment supplier and / or operator.

**NOTE** This is typically every 1000 ft to 1500 ft. If the checks require access to the cable ends, for example to disconnect/reconnect them, then the operator may consider increasing the check interval to reduce the number of times this shall be done.

- 1) Check all three phases of the cable for current and / or both phase to phase and phase to ground measurements at the spooler for voltage as applicable to the method applied to the cable ends.
- 2) If the leads are shorted, some integrity checks may require disconnecting the short and isolating the leads from each other (such as any phase-to-phase checks). In this situation, each lead shall be checked for current flow as there may not be any phase to ground voltage to measure even if the unit is rotating. In addition, the act of disconnecting the leads while the unit is rotating may cause significant sparks.
- 3) If the leads are isolated from each other, there will generally not be any current flow path. In this situation, each of the leads shall be checked for both phase to phase and phase to ground voltage.



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- 4) Continuous monitoring equipment may not require disconnection for most integrity checks.
- h) Refer to the PMM equipment supplier guidelines for any installation speed limitation requirements or recommendations.

#### **8.4.4 Landing of equipment**

Once the equipment is landed, a final electrical system integrity check is typically performed. This should be performed per step 8.4.3g.

#### **8.4.5 Wellhead installation**

Any splicing and penetrator connection is to be performed per section 14. The cable from wellhead penetrator to the JB should be connected at the well head. The free end should be prepared for connection to the JB terminals, but not connected at this stage. The cable conductors should be insulated or shorted and grounded then located to avoid accidental contact.

#### **8.4.6 Commissioning**

Proceed to commissioning per section 10.

### **8.5 Cable Deployed**

Typically, the deployment of this type of ESP is done as a complete electrical submersible assembly where the pump is coupled to the motor and there is risk of unplanned motor rotation creating EMF. Due to this, it is recommended to observe all applicable precautions and mitigations listed for conventional deployed ESPs.

### **8.6 Through Tubing Deployed – Threaded or Coupled Tubing**

Typical running in hole is done in stages:

- a) The motor assembly, without pump, is lowered into the tubing and landed. There is no risk of electrical shock as there is no mechanical linkage to turn the motor shaft.
- b) RIH of the pump assembly inside the tubing. The pump may spin as it is lowered through fluid in the tubing but since it is not mated to the motor there is no risk of electrical shock.
- c) Once the pump is landed and coupled to the motor, caution shall be observed for any action or process at the wellsite which allows the pump to rotate. It is recommended to observe all precautions and mitigations listed for conventional deployed ESPs once this connection is made.

If the pump has not yet been coupled to the motor, then final electrical checks, gauge checks on the motor, makeup of penetrator connections and splices can be done with no risk of electric shock as there is no mechanical linkage to spin the motor shaft.

Proceed to commissioning per section 10.

### **8.7 Through Tubing Coil Tubing Deployed – External Cable**

Typically, the deployment of this type of ESP is done while the pump is coupled to the motor as an assembly. Since the pump is connected to the motor, there is risk of unplanned motor rotation creating EMF. Due to this, it is recommended to observe all precautions and mitigations listed for conventional deployed ESPs.

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## **8.8 Through Tubing Coil Tubing Deployed – Internal Cable**

Typically, the deployment of this type of ESP is very similar to the external version discussed in section 8.7 with the pump coupled to the motor as an inverted assembly with the pump at the bottom of the assembly. Since the pump is connected to the motor, there is a risk of unplanned motor rotation. Due to this, it is recommended to observe all precautions and mitigations listed for conventional deployed ESP.

## **8.9 Docking station deployed**

Installation of single or modular stage docking station systems consist of a permanent outer completion (dock) with ESP power cable deployed on tubing and an inner completion comprised of the retrievable ESP assembly. They are typically deployed through the tubing by wire line (slick line, braided line, or electric line) coil tubing or sucker rod. Depending on the selected supplier's docking station system, the wet-mate connection may be internal or external. One supplier system may utilize either IM or PMM type ESP motors while another supplier may just utilize PMM type ESP motors. In the case of the modular stage PMM-ESP, install by slickline is most common since the weight per run is lower.

### **8.9.1 Single stage PMM ESP system**

#### **8.9.1.1 Deployed with the tubing and ESP power cable as an assembly**

There exists potential risk for shock from EMF resulting from unplanned fluid movement in either direction. Rotating the pump will spin the motor shaft and generate voltage at the cable terminals. It is recommended to observe all precautions and mitigations listed for conventional deployed ESPs.

#### **8.9.1.2 Deployed Separately from the tubing and ESP power cable:**

There is no risk for shock from EMF resulting from unplanned fluid movement in either direction. Once the ESP is landed in the docking stations and the motor is connected to the docking station terminals there is potential risk for electric shock from EMF resulting from unplanned fluid movement in either direction. Rotating the pump will spin the motor shaft and generate voltage at the cable terminals. It is recommended to observe all precautions and mitigations listed for conventional deployed ESPs.

### **8.9.2 Modular stage PMM ESP system**

#### **8.9.2.1 Deployed with tubing and ESP power cable as an assembly**

There exists potential risk for shock from EMF resulting from unplanned fluid movement in either direction. Rotating the pump will spin the motor shaft and generate voltage at the cable terminals. It is recommended to observe all precautions and mitigations listed for conventional deployed ESPs.

#### **8.9.2.2 Deployed separately from the tubing and ESP power cable**

There is no risk for shock from EMF resulting from unplanned fluid movement in either direction. Once the ESP is landed in the docking stations and the motor and pump is connected to the docking station terminals there is potential risk for electric shock from EMF resulting from unplanned fluid movement in either direction. Rotating the pump will spin the motor shaft and generate voltage at the cable terminals. It is recommended to observe all precautions and mitigations listed for conventional deployed ESPs.

#### **8.9.2.3 Deployment runs**

Modular stage PMM-ESPs are normally installed in four runs:

- a) Sensor gauges, PMM, protectors, and lower mating unit.
- b) Upper mating unit, pump intake with optional gas separator / gas handler, pumps, discharge head and Polish Bore Receptacle.
- c) Stinger seal, spacer pup joint, standing valve, and pack-off.

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d) Tubing stop.

### **8.9.3 Docking stage summary**

- If the docking station, tubing, and cable are RIH WITH the PMM-ESP landed in the docking station, the risk of EMF exists any time there is fluid flow in either direction through the pump.
- If the docking station, tubing, and cable are RIH WITHOUT the PMM-ESP landed in the docking station, there is no risk of EMF until the ESP is landed and docked.
- The risk of electric shock and arc flash from EMF by fluid flow in either direction through the pump is a common risk to both deployment types when the motor(s) are coupled to the pump and landed in the dock during installation.
- With the modular stage docking system the risk of EMF exists once the motor and pump are landed even if the seal sub and tubing anchor are not yet set or have been removed.

## **8.10 Surface PMM**

PMMs may be deployed as a direct drive system when coupled to the PCP rod string or SRP.

PMM at the surface does not possess an electrical risk when performing a RIH installation. The motor and its mechanical linkage are disconnected from the wellbore in both PCP and SRP systems.

Once the mechanical linkage is made to the PMM there is a potential risk of hazardous electrical shock from PCP rod rotation. There is EMF risk in SRP systems once the mechanical linkage is made, however, personnel should be outside the danger zone of the crank arms.

### **8.10.1 PCP installation safety measures**

LOTO is performed at the utility source. For surface driven PCP systems, the motor is connected to the surface drive unit. The motor is removed before well servicing.

Electrical checks regarding PCP: With rotor at full stop, ensure a safety clamp is installed close BOP or rod locking BOP (if available) or rod lock to avoid mechanical injuries and generation of hazardous voltage. Remove the terminal box cover and check the resistances of the stator winding between the three phases (P-P) and the insulation resistance between the phases and the stator housing/ground (P-G) in the motor terminal box. Use appropriately rated voltage test equipment and PPE as described in Annex B and Annex C respectively.

### **8.10.2 SRP installation safety measures**

Under no circumstances should well intervention be attempted without first removing the horsehead, as doing so breaks the mechanical linkage of the rod string and pump. However, mechanical links to the PMM still exist from crank weight movement.

**WARNING**—working inside the crank weight zone with unsecured cranks can be fatal if struck. When working near rotating elements, be certain that the driving and driven equipment are securely locked out.

Safety begins with stopping the unit with the walking beam in a near level position and the cranks pointing away from the well. It is recommended to set the brake and use the locking pawl to prevent all motion. Once the locking pawl is engaged, LOTO of energy sources is performed at the energy sources (utility and vented JB).

Next, the well load is clamped off by placing a polished-rod clamp at the stuffing box and tightened according to the clamp supplier's torque recommendations. Place a properly rated high-grade alloy chain through the holes in the brake drum nearest the trunnion and then around the trunnion. Snug up the chain and attach the hook end around a link. Be sure the chain is working against the direction of unit rotation so that the horsehead moves down with cranks moving up, otherwise when the unit brake is

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released, the chain will be under extreme tension. If you need to “bump” the cranks with momentary power (off/on/off) you may snap the chain and risk injury and/or equipment damage when the cranks move down as the horsehead moves up.

Keeping the (hand) brake engaged, remove the other safety precautions for securing against crank rotation. Slowly release the brake to lower the cranks to the bottom position (sometimes termed “6 o'clock” position). Reinstall safety precautions with the pawl and chain before well servicing. Only then may PMM work commence.

When all work is completed and before turning the unit power on, be sure the chain is removed.

SRP insulation checks on a PMM are not applicable because of the motor housing obstruction. No voltage or current generation from motion is possible as the PMM is disconnected from all mechanical linkage.

## **9 Pull Out of Hole (POOH)**

### **9.1 General**

POOH may be performed for many reasons, including replacing leaking tubing, changing equipment specifications (for example a different pump), or recovering a damaged installation. Job safety planning and the job safety briefing will include detailed consideration of the PMM issues that may have arisen with a damaged installation.

The scope of this section starts with the PMM installed in the well and potentially connected to the surface electrical equipment. It includes the general steps of isolating the surface equipment at the JB, removing the wellhead feedthrough, raising the equipment from the well while re-spooling the (possibly damaged) cable, dismantling the BHA and preparing the retrieved equipment for transport from the wellsite.

### **9.2 POOH-specific job safety planning**

The following topics should be included in job safety planning (section 5). Damaged cable can give rise to changeable electrical conditions. Prevention of rotation devices may not work as intended. Planning should include corresponding mitigating actions.

A primary consideration for pulling a PMM systems is the possibility of sparks being generated in the hazardous area as the feedthrough and cable components are retrieved from the well.

### **9.3 Operator Planning and Notification of Pending Pull**

If the electrical system is damaged, additional considerations apply to safe POOH practice. Consequently, the electrical condition of the installed equipment should always be established first.

This may require electrical measurements to be made (see section 11).

The reason for the pull of a PMM system, and the electrical equipment condition, should then be communicated to the service suppliers.

### **9.4 Electrical damage**

Examples of downhole damage from just below the well head to within the motor itself include:

- All three phase conductors are severed.
- All three phase conductors are effectively shorted together.
- There is a ground fault.
- A mixture of the above on one or more conductors.
- Intermittent connection.

If the cable has parted on one or more conductors there is a potential spark hazard when the faulty location emerges at the wellhead unless it can be verified that the motor is above fluid level.

A TDR or resistance measurements may be helpful in determining the location of a cable fault (see section B.7.2), and whether it is near the well head or near the motor, which are common points of failure. If near surface, the faulty section can be rendered safe during initial pull. If near the motor, there is potential for voltage to be generated throughout the pull. The TDR test could be repeated when a damaged section of cable is removed. Before using a TDR, the cable shall be checked for absence of voltage (section 14.3).

If the location of the fault can be determined from TDR, then it is recommended to slow the rate of pull as the fault approaches the fluid level, and then to continue pulling slowly until the motor is above the fluid level.

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A pump-down test to see if motor rotation can be detected by surface measurements should be considered.

## **9.5 Prevention of rotation**

If no prevention of rotation devices are installed, then it is recommended to consider installing a tubing plug or slickline deployed tubing packer above the pump or perforating the tubing above the pump.

This may be unnecessary if it is possible to detect rotation using surface measurements, such as in an undamaged or slightly damaged electrical system.

## **9.6 Feedthroughs**

After LOTO of the drive supply, disconnect the ESP power cable from the vented JB (section 14.3). Insulate the cable end and protect from incidental contact.

Disconnection and removal of the feedthrough is dependent on penetrator type and supplier procedures (section 14.8).

**CAUTION**—If the cable end is temporarily shorted for any reason, it shall not be disconnected from the feedthrough until the short is removed and the end insulated. Disconnection of a shorted cable at the wellhead is likely to create sparks if there is unplanned motor rotation when the cable is detached.

Once the penetrator is removed, the ESP power cable end can be laid down in the non-hazardous area and safely terminated by insulating the ends or by shorting and grounding to the armor.

## **9.7 Spooler**

For POOH, the ESP power cable will need to be transferred to the spooler.

The cable end can then be transferred to the spooler. It is recommended to short and ground the cable end within the cable reel and use continuous monitoring for any signs of rotation. This is recommended even if the downhole portion of the cable is damaged since damage is changeable during POOH.

## **9.8 Retrieval**

It is assumed that all the steps outlined in section 7 are completed prior to the commencement of POOH.

Personnel will have been briefed on the electrical condition of the system and special procedures that may apply.

If installed, the prevention of rotation device(s) should be activated and tested. Alternatively, the job plan may include a procedure such as perforating the tubing in the event the devices fail to operate (for example, a washed out check valve).

## **9.9 Intact Electrical System**

When the electrical system is intact, the process is largely the inverse of RIH (section 8), starting with isolating the surface equipment, removing the penetrator, and re-spooling the ESP power cable as the tubing is pulled.

If continuous monitoring for detection of unplanned motor rotation was included in the job plan, it will be helpful in ensuring POOH speed is not too high.

It is recommended to short and ground the cable at the spooler and to use continuous monitoring for detection of unplanned motor rotation. If continuous monitoring is not available, prepare the cable ends per manufacturer guidelines for the operation to be performed.

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## **9.10 Damaged Electrical System**

The workflow is the same as for an intact system.

In some cases of electrical damage, continuous monitoring at the cable end can detect unplanned motor rotation. This includes a simple ground fault or a disconnected phase.

Although shorting and grounding will eliminate voltage at the cable end, a damaged location emerging at surface may have voltage, with the additional risk of sparks. (See I.4 for examples of voltage on damaged cable.) Depending on the severity of the damage, the cable should be taped before laying down in the safe area. It can then be cut, the end made safe, and re-spooled.

## **9.11 BHA at surface**

Once the pump is at surface with the intake above the wellhead, there are no electrical hazards during dismantling of the BHA.

If no motor failure is suspected, it is normal to remove the MLE and fit a pothead cap. The motor head is then capped, and the motor removed from the well and laid down.

If there is a suspected motor failure, normal practice is to cut the MLE 1 – 2 ft above the motor pothead for subsequent shop DIFA. Since the motor head is capped before removal from the well, preventing externally caused motor rotation, there is no risk associated with this cable stub.

If it is desired to over-wrap the cable stub with insulation, care should be taken to not disturb any evidence that might be useful in subsequent failure analysis.

## **9.12 Conventionally Deployed**

There are no specific recommendations additional to sections 9.1 to 9.13.

## **9.13 Completion**

With the BHA components laid down, there are no remaining electrical hazards. Rig down the installation equipment, clear the wellsite, and hand over to the responsible person.

There are no electrical hazards in handling and transporting the motor. If air transport is required, see section 6.6.

## **9.14 Cable Deployed**

Typically, the downhole electrical submersible assembly is retrieved as a complete assembly, with the pump coupled to the motor. Due to this, there is risk of unplanned motor rotation and subsequent EMF generation. It is recommended to observe all applicable precautions and mitigations listed for pulling conventional deployed ESPs.

## **9.15 Through Tubing Deployed – Threaded or Coupled Tubing**

Risk of electric shock will depend on the pull out of hole (POOH) philosophy.

### **9.15.1 Retrieve as a complete assembly**

If the ESP system is retrieved as a complete assembly (while the pump is connected to the motor) then the risk of EMF is high.

There are no specific recommendations additional to sections 9.1 to 9.13.

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#### **9.15.2 Retrieve pump and motor separately**

If the pump assembly is uncoupled from the motor and retrieved separately, then the risk of electric shock has been eliminated, as there will be no shaft rotational movement in the motor.

CAUTION—Prior to uncoupling the pump from the motor, care should be taken during any work on the ESP power cable and penetrator. The same precautions as a conventional deployed ESP should be observed until the pump is successfully proven to be uncoupled from the motor.

#### **9.16 Through Tubing Coil Tubing Deployed – External Cable**

The downhole assembly is retrieved with the pump coupled to the motor. Due to this, there is the risk of unplanned motor rotation and subsequent EMF generation

There are no specific recommendations additional to sections 9.1 to 9.13.

#### **9.17 Through Tubing Coil Tubing Deployed – Internal Cable**

The downhole assembly is retrieved with the pump coupled to the motor. Due to this, there is risk of unplanned motor rotation and subsequent EMF generation.

There are no specific recommendations additional to sections 9.1 to 9.13.

#### **9.18 Docking Station Deployed**

##### **9.18.1 POOH Single Stage Dock Deployment System**

Retrieval of the ESP System may be performed in two ways:

- Disconnection of the retrievable assembly from the docking station. This breaks the electrical connection between the motor and docking station ESP power cable, so removing the risk of EMF.

CAUTION—Prior to undocking (lifting) the retrievable ESP assembly from the docking station, care should be taken during any work on the ESP power cable and penetrator. The same precautions as a conventional deployed ESP should be observed until the pump is successfully proven to be uncoupled from the motor.

- Retrieval of the complete BHA and tubing without first retrieving the ESP, as part of the rig-assisted tubing retrieval operation. The risk of electric shock and arc flash remains. It is recommended to observe all precautions and mitigations listed for conventional deployed PMM-ESPs.

##### **9.18.2 POOH Modular Stage Dock Deployment System**

Retrieval of the ESP System may be performed in two ways:

- Disconnection of the pump from the motor to retrieve the pump using wire line. This eliminates the risk of unintended motor rotation.

CAUTION—Prior to undocking (lifting) the pump from the motor, care should be taken during any work on the ESP power cable and penetrator. The same precautions as a conventional deployed ESP should be observed until the pump is successfully proven to be uncoupled from the motor.

- Retrieval of the complete BHA and tubing without first retrieving the ESP, as part of the rig-assisted tubing retrieval operation. The risk of electric shock and arc flash remains. It is recommended to observe all precautions and mitigations listed for conventional deployed PMM-ESPs.



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## **9.19 Surface PMM**

POOH for surface deployed SRP and PCP begins with bringing the PMM to a full stop and following safety procedures as mentioned in section 8.10. Ensure electrical sources at the utility and JB are disconnected and employ LOTO.

### **9.19.1 PCP systems**

PCP systems should use either a safety clamp and closed BOP or a rod string locking BOP (if available) to avoid mechanical injuries and potential electric shocks. Then the mechanical linkage related to the PMM may be disconnected.

Belt driven or direct-drive PCP transmissions need to observe caution before removing the surface drive unit to which the PMM is attached. A PCP system should be allowed to fully equalize to minimize the possibility of breakaway speed creating a backspin with EMF (see also 5.10). Once the PMM is unlinked from the rod string there is no further electrical risk.

### **9.19.2 SRP Systems**

SRP systems shall have the crank weights safely secured to prevent hazardous injury or fatality from being struck while working inside the crank arm danger zone.

PMM-SRP are normally direct-drive but in some instances the PMM may be substituted for the IM and utilize a belted transmission. Insulation checks are not possible due the PMM housing construction.

Checks to verify no current or voltage are to be made at the JB.

## **10 Commissioning**

### **10.1 General**

Commissioning is typically, but not always, performed consecutively with completion of RIH. This section assumes that the steps in section 8 were performed, the wellhead connection to the downhole cable has been made, and the connection to the JB is not made.

If the interconnections of the drive, transformer and JB have not been made, they should now be performed according to section 13.

**WARNING**—Unplanned motor rotation resulting in potentially lethal voltage at surface is a possibility during Commissioning. This can arise from well kicks and from backspin following an attempted start.

See section 7 for pre-commissioning work review and preparations. If commissioning is performed in the same work period as RIH then this should have already been done.

### **10.2 Recommended workflow**

Some of the following steps may vary in order or not be required depending on special case situations such as when reprogramming of the drive is required. It is assumed that the steps outlined in section 7 have been completed before proceeding with the steps given below and summarized in workflow Figure 8.

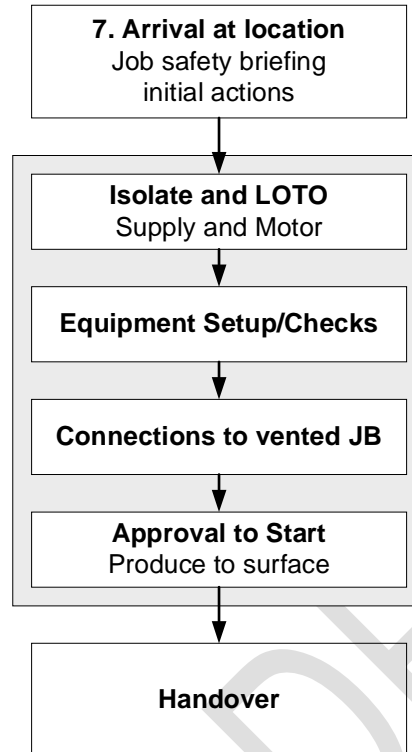


Figure 8—Commissioning workflow.

### 10.3 Electrical isolation / LOTO Verification

Confirm or perform LOTO of both surface and downhole power sources.

- a) Ensure the surface pigtail is disconnected from the JB. The cable ends should be prepared by either insulating or shorting and grounding the conductors and positioning to avoid accidental contact.
- b) The VSD and transformer and JB are now isolated from both sources of power, the supply, and the motor.

### 10.4 Equipment setup / checks

Follow supplier drive and transformer detailed checking procedures, typically working from the drive towards the JB as follows:

- 1) Ensure the step-up transformer is not connected to the drive.
- 2) Remove supply LOTO and energize the drive.
- 3) Configure or modify parameters in the drive as necessary.
- 4) De-energize and isolate the drive and connect the transformer.
- 5) Energize the drive and check the transformer output voltages are balanced and correct.

**WARNING**—Use properly rated test equipment to perform voltage checks to avoid damage and or injury.

- 6) De-energize the drive and LOTO the supply power.

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- 7) Connect the transformer secondary to the vented JB.

## **10.5 Connections to vented JB**

Connections to the vented JB should follow the guidance below.

- 1) Check the surface pigtail of the ESP power cable is not energized prior to making any further measurements that may be required and before (re)connecting in the vented JB.
- 2) If isolation or grounding switches are used at the drive output and/or transformer secondary, some of the above disconnect/re-connect steps may be omitted. Use LOTO on these switches.
- 3) All electrical terminations are now complete and enclosure access doors, covers, etc., closed. Once complete, the following can be performed:
  - a) Clear the spooler from the area.
  - b) Ensure all required signage is in place (see Annex E).
  - c) Remove access barriers.

## **10.6 Start-up preparation**

The responsible person should ensure ongoing coordination with any control room personnel. If downhole prevention of rotation devices are installed, set them to their state for normal pumping. Check and verify on location that the wellhead flow line valve is open. Remove supply LOTO and energize the drive.

## **10.7 Start-up**

With the approval of the responsible person, start the PMM ESP system.

If the motor is determined to be turning in the wrong direction, stop the VSD, and wait for backspin to complete. This is preferably done using drive rotation sensing but may also be done by voltage measurement. Phase sequence correction:

- a) It is recommended to reverse direction using the drive controls or as per supplier guidelines. It is recommended that the reversal be documented in the drive so that if it is replaced, the phases can be connected correctly.
- b) Physically swapping phase conductors has the advantage that the conductors can be correctly labelled, however doing so can expose the worker to energized conductors thereby creating an electrical hazard. Check for no rotation and use safe cable handling practice.

## **10.8 Handover**

When fluid is at surface and producing, clean up and hand-over to the responsible person.

Commissioning is now complete.

## **11 Ongoing operations and maintenance**

### **11.1 General**

This section describes recommended practices when performing maintenance or troubleshooting work on wells having PMMs installed as part of the artificial lift system.

The arrival at location procedures (section 7), including the job safety briefing, should have been completed prior to beginning any maintenance activity.

### **11.2 Maintenance-specific job safety planning**

The following is only applicable when access to electrical conductors is necessary. Any work performed on the HMI of the drive that does not require electrical conductor access is to be performed in the same manner as for conventional induction motor systems.

Prior to beginning work on any installed ESP system, it is important to plan and understand what steps are to be performed. The following topics should be considered during job safety planning (section 5):

- a) The equipment in the well shall be confirmed during planning and re-verified on location.
- b) When conducting ongoing and/or maintenance operations with the drive supply isolated and LOTO, the additional risk to personnel comes from the EMF generated by potential unplanned motor shaft rotation while performing troubleshooting, maintenance, or repair operations on surface equipment.
  - 1) Activate and test any installed prevention of rotation devices.
    - This may not be possible for some types of troubleshooting, or with limited surface equipment and personnel availability (see section 14.1).
  - 2) For work on surface equipment, disconnect and LOTO the surface pigtail at the JB.
    - Any conductor should be considered energized until proven otherwise as stated in section 4.
  - 3) Ensure that no SIMOPS are conducted that could lead to unintentional motor rotation during any of the maintenance or troubleshooting steps to be performed. Any such operations that could lead to motor rotation (such as acidizing, hot flushes, or other fluid injection operations) are to be coordinated to avoid simultaneous work being performed.
- c) Some tasks may be on running systems, such as checking a suspected faulty step-up transformer for secondary-side voltage balance, under load. If electrical work is essential, safe electrical practices shall be followed as if for unplanned motor rotation. An arc in the vented JB may originate from the motor, whereas the drive electronic protections should operate and almost instantly prevent the drive out putting a fault current.
  - A running system necessarily implies that any prevention of rotation device is inactive.

### **11.3 Access to Surface Electrical Connections**

Prior to accessing any electrical connections:

- a) Wear necessary PPE for each task performed (see Annex C).
- b) Confirm availability of appropriate instruments and confirm proper operation (see Annex B).
- c) Verify appropriate access control measures and signage are in place (section 7.8).
- d) Ensure any downhole prevention of rotation device is activated and tested.
  - For some types of surface maintenance live working could be considered for measurements in accordance with national and local regulations (see 14.3).
- e) Ensure flow line and casing valves are shut, to prevent fluid flow in either direction.
- f) Until proven otherwise, assume any conductor is energized.

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- g) Perform isolation and LOTO of the drive from the power supply.
  - Verify absence of voltage using live-test-live methodology.
- h) Perform isolation and LOTO of the surface unit to be evaluated from the downhole equipment.
  - If disconnecting the downhole equipment at the JB, insulate the surface pigtail conductors of the pigtail and keep them positioned securely in the non-hazardous area.
  - If installed, use the isolating and/or grounding switch to disconnect the motor (and confirm that the switch has performed as intended). This enables safe work between the supply isolation point and the motor switch.
- i) If available, use safe monitoring points on JB's and other installed surface equipment to establish whether there is voltage before opening.

## **11.4 Surface PMM**

### **11.4.1 Surface driven PCP electrical checks**

Unlike conventional ESP centrifugal pumps, the PCP is a positive displacement type pump. Thus, any downhole fluid movement is likely to cause the pump to rotate and subsequently cause EMF generation by the motor. The voltages created may significantly exceed the nameplate rating if sufficient fluid movement occurs to rotate the pump faster than the rated nameplate speed. The generated voltage will depend on the motor type and rotation frequency (typically from 0.1 V to 2 V per rpm).

**WARNING**—PCP maintenance work should never be performed when the drive head is operating.

If the motor needs servicing or troubleshooting, the following procedure is recommended in addition to section 11:

- a) After the power supply has been disconnected and LOTO, verify no text is visible on the control panel, and the main circuit voltage is zero.
- b) Visually confirm the gearbox for zero shaft rotation. To further reduce the possibility of backspin, wait enough time for the fluid column in the tubing to equalize after turning off the unit. See section 5.4.7 for guidance.
- c) Install a safety clamp and close the rod BOP or close the rod locking BOP.
- d) Perform the motor or VSD checks.
- e) To bring the unit back online perform the sequence in reverse.

### **11.4.2 SRP Beam Units**

PMM-SRP are normally direct-drive applications with no belts. Figure 9 shows a comparison between a conventional IM belt driven transmission and a PMM direct drive. In some instances, the PMM may be swapped out with the IM and use a belt transmission. In this case the safety procedures are the same as the conventional IM. The procedure discussed below is for a direct drive PMM system.

**WARNING**—Personnel should never be inside the danger zone of the rotating equipment and crank arms unless the crank weights have been secured.

The primary instance of EMF generation occurs when the unit is stopped, and the crank weights fall/swing to the six o'clock (weight heavy) or 12 o'clock (Rod Heavy) positions. If a check of the motor is necessary, then proceed with confined space and overhead objects awareness; ensure proper ingress and egress. Wear required PPE for each step of the procedure.

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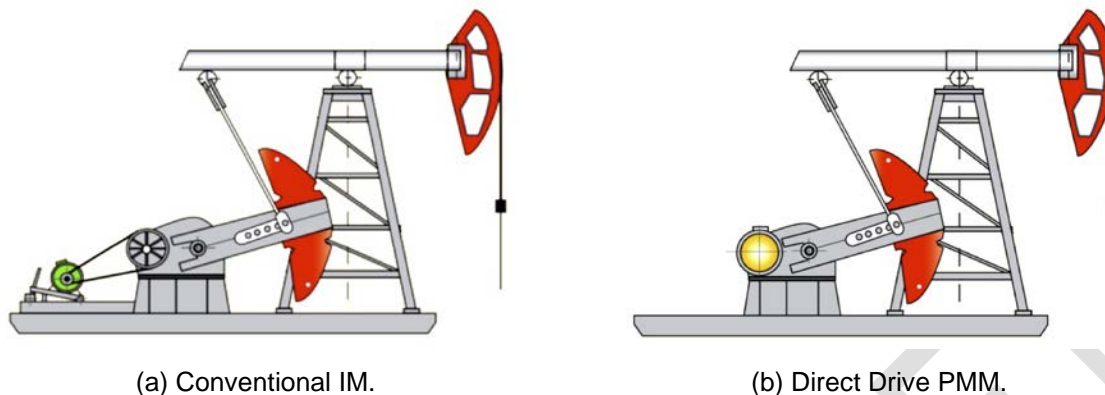


Figure 9—Sucker Rod Unit transmission types.

Before performing electrical checks, the SRP system shall have the crank weights safely secured to prevent personnel injury or death from being struck by cranks while inside the danger zone. Unsecured cranks can lead to pumping unit linkage movement (crank arms and weights) if pump valves leak, or the brake is inadequate. It is critical to ensure the drivetrain components are securely locked out.

If checking the motor of an operational unit, stop the crank weights in a level position or six o'clock position of the rod upstroke. Set the brake and turn the hand-off-auto (HOA) switch, or its equivalent, to OFF. Then disconnect power at the utility source and use LOTO at the utility pole and JB. Test the electrical and control equipment to ensure no power is available to the motor. Next, secure the unit brake drum with the pawl and dog (or brake lockout bolt). If using chain, string a load rated high tensile alloy chain through the hole in the brake drum nearest the brake trunnion and then around the trunnion itself, tighten the chain and attach the hook end around a link. If PMM housing obstructs ability to perform insulation checks then checks to verify no current or voltage condition are to be made at the JB.

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## **12 Well control or cable damage**

### **12.1 General**

This section covers exceptional circumstances that may occur during well operations other than normal running: RIH, POOH, commissioning or troubleshooting and maintenance. Consideration of these circumstances is an essential aspect of job safety planning and the arrival at location job safety briefing.

### **12.2 Well control**

In the event of a well-kick requiring emergency shut in of the well, sealing of the cable running through the BOP shall be addressed.

### **12.3 Sealing over cable**

It is recommended that an annular BOP is included in the BOP stack, with a sealing element that is suitable for the ambient temperature. It may be necessary to use a natural rubber element at depressed temperatures. Ram blocks that have been modified for ESP power cable are not as effective as an annular BOP.

A pipe RAM will not seal on an ESP power cable.

### **12.4 Cutting cable**

It is not recommended to cut the cable during a well control event unless:

- a) a prevention of rotation device is installed and tested (see section 5.4) and/or
- b) it can be established during planning that there is no risk of explosion from sparks that could arise from an energized cable being cut or sheared.

After the well control event is over, and the well has been stabilized and shut, a cut cable shall be made safe. Using safe electrical practices (section 14.3) insulate the individual phase conductors ends.

**NOTE** Well control with SRP or direct drive PMM linear rod lift is not normally applicable as the pump reciprocates via mechanical linkage over a fixed stroke length. In the rare event of a strong well kick or parted rods situation causing upward sucker rod movement, the PMM may go into generative mode duration of the stroke length only.

**WARNING**—Personnel should never be inside the hazardous area of a running or idle (time clock/pump-off control) sucker rod pump unit.

**WARNING**—Linear lift systems, like PCP, are “walk-up” approachable and care needs to be exercised before touching these PMM driven systems to avoid electrical shock or electrocution.

### **12.5 Cable damage at surface**

The ESP power cable can be damaged with the slips or tongs during RIH or POOH. If there is unplanned motor rotation and conductors are exposed, there is a hazard from EMF both to workers and from sparks or arc flash if there are flammable gases present.

Section 5.4 covers selection of equipment for deployment in the well that can be used to prevent motor rotation during RIH and POOH.

Through proper equipotential bonding and grounding practices, the electrical hazards will generally be mitigated. However, inadvertently touching exposed energized conductors in the damaged part of the cable can result in an electric shock and severe injury.

**NOTE** POOH of a damaged cable is considered in section 9.



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## **12.6 Cable Damage – Specific Safe Work Practices**

Job safety planning should consider what action will be taken in the event there is damage to the cable on the rig floor. Possible actions include:

- The crew will stand back while the task qualified person evaluates the damage and makes safe as required. Section 14 covers recommended practices for cable operations.
- Having ready a tubing plug or stabbing valve that can be set immediately to stop rotation.
- Rapidly pull up a stand and lay the cable down outside the hazardous area.

## **13 Surface electrical equipment**

### **13.1 General**

Typical surface electrical equipment includes the following:

- Step down transformers (converting line voltage to allowable drive incoming voltage)
- Variable speed drive (VSD) or adjustable speed drive (ASD) or variable frequency drive (VFD) or adjustable frequency drive (AFD).
- Step up transformer
- Vented JB

These components are illustrated in Figure 10.

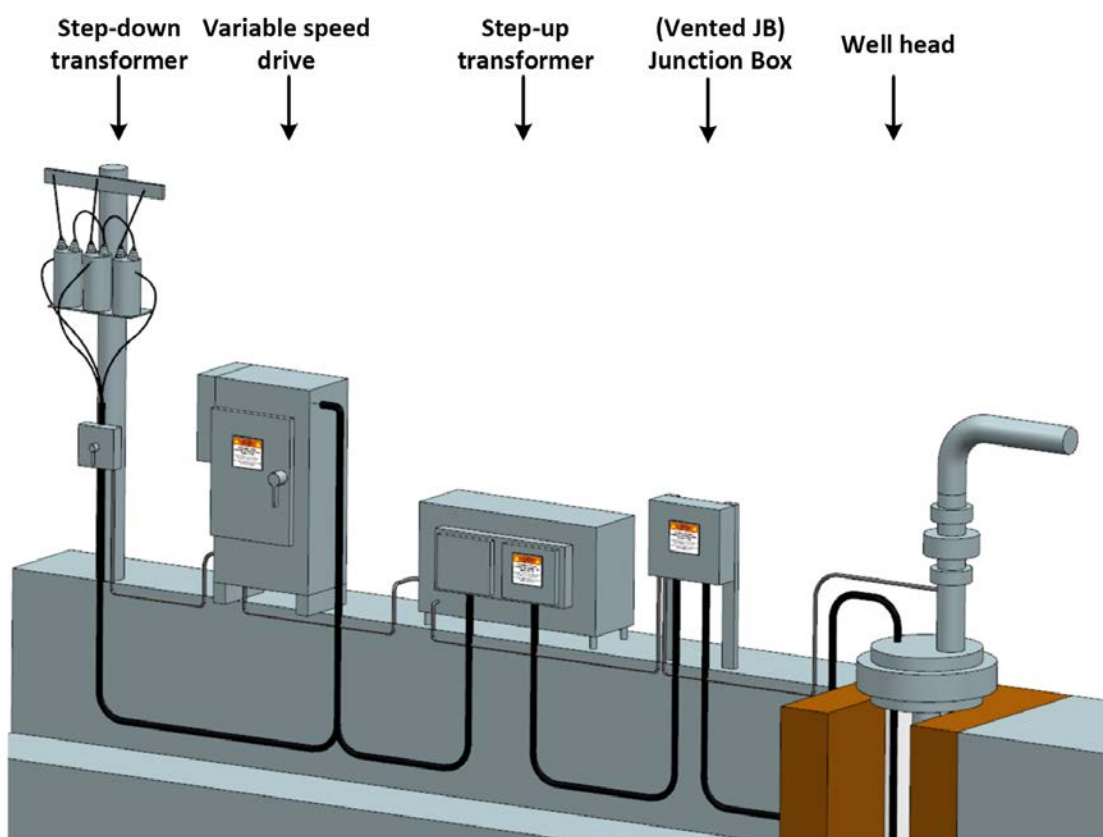


Figure 10—Typical surface electrical equipment.

Situations may vary from this configuration, such as not requiring a step-up transformer with a particular medium voltage drive or with direct downhole drive PCs.

During unplanned motor rotation, these surface components may become energized up to the output of the variable speed drive. Depending on the drive internal design, this could even back feed through the drive and harm various internal components. Due to this, the entire system should be considered as an energized system or one that could become energized at any time. Both the line side and motor side can contribute power to any of these components and thus both shall be considered (unlike conventional induction motor applications where only the line power is typically considered).

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In this document the (vented) JB is frequently used to designate in the non-hazardous area, the first point of connection/disconnection of the ESP power cable. If this JB is not installed, the first point of connection/disconnection would move to the secondary of the step-up transformer. If a step-up transformer is not used, it would move to the drive output JB. It is important that the JB used be suitable for LOTO.

The following are recommendations to mitigate the risks within the surface electrical equipment associated with the EMF generated by unplanned motor rotation:

### **13.2 Drive selection and use with PMMs**

When selecting a drive for use with PMM's, the following considerations should be made:

- a) Drives should monitor the motor for rotation, for example backspin speed, even when stopped.  
When the drive is powered on, drive measurements can be used as a presence of rotation indication until backspin or a well kick has subsided to a low level, so helping to avoid premature access to electrical connections or other operations.
- b) Drives should be able to detect and trip in the event of stalls and other special issues.
- c) Drives should not allow any EMF from the motor side to feed through the drive from the output to the input (or to other critical components such as the HMI or power module.)
- d) Drives should be able to withstand voltage from backspin or regenerating PMM. This may include a means of voltage limiting.

### **13.3 Accessing equipment**

Prior to accessing any electrical equipment, certain steps should be performed to ensure personnel safety. These steps include:

- a) Disconnect and perform LOTO on both the line side and the downhole side prior to opening any surface equipment.  
Use disconnect or shorting switches where provided on the load side of drive (complementary to supply-side switches).
- b) During maintenance, a cable check at surface is performed by removing the leads at the drive JB, transformer step-up chamber, or vented JB between transformer and wellhead. Terminations that allow for minimal conductor contact for removal are preferred.
- c) Prior to contacting any conductor to disconnect it, verify that it is not energized utilizing an appropriate instrument per Annex B.
- d) Refer to the sections covering recommended practices for PPE, grounding, and signage.

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## **14 Cable operations – spooler, cutting, splicing and feedthroughs**

### **14.1 General**

The cable operations considered in this section are operations that are performed directly on the ESP power cable during RIH, POOH and maintenance/troubleshooting. These operations have significant potential to bring personnel into proximity with potentially live conductors caused by unplanned motor rotation. The use of prevention of rotation devices (see section 5.4) will in most circumstances significantly reduce this risk. It is nevertheless recommended to always follow safe electrical practices.

**NOTE** When a submersible pumping system is operating, the electrical system is known to be live. The electrical procedures are the same as for non-PMM systems during the operation of the system.

### **14.2 Electrical power system one-line diagram**

During job planning, the installation electrical one-line diagram is reviewed. An example of a basic diagram is shown in Figure 11. This figure includes a list of items. A full diagram with itemized notes will list the specific types of equipment and cables. The equipment supplier's application engineering report will include full details of the BHA.

In most cases, the operator is responsible for placement of the surface equipment, for the incoming supply [item 1] and for connections from the supply through to the step-up transformer primary [items 2-4]. Standard practices are used for the type and sizing of cables and grounds.

The PMM supplier will provide the motor electrical details, the recommended ESP power cable size, initial step-up transformer secondary tap voltage and expected full load motor current.

The cable feedthrough rating is selected by the operator based on the above information. Installation procedures for these critical devices needs careful consideration in PMM systems (section 14.8) and may affect the equipment type that is selected.

Item 6 is the recommended location for isolation of the surface equipment from the supply, and LOTO.

Item 13 shows possible locations for an isolation/LOTO switch which would prevent PMM EMF from entering the drive. With LOTO of Item 6, the drive should be electrically safe to work on. A medium voltage switch between the transformer and JB could allow safe-de-energized working on the transformer. Another possible location for this switch is integral to the transformer.

Step-up transformers typically use off-load (de-energized) tap changers. For these transformers, tap changing is always performed with the drive stopped or switched off. Because of the possibility of PMM EMF, the output of the transformer shall be isolated as well, for example by disconnection at the vented JB.

**NOTE** if the tap changer handle does not expose the technician to electrical connections, a test for EMF such as by drive monitoring or by measurement at the vented JB may avoid the need to isolate the motor.

**NOTE** In some cases, for example an oil-immersed tap changer, the manufacturer may expressly allow voltage to be present, but not load current, when changing taps.

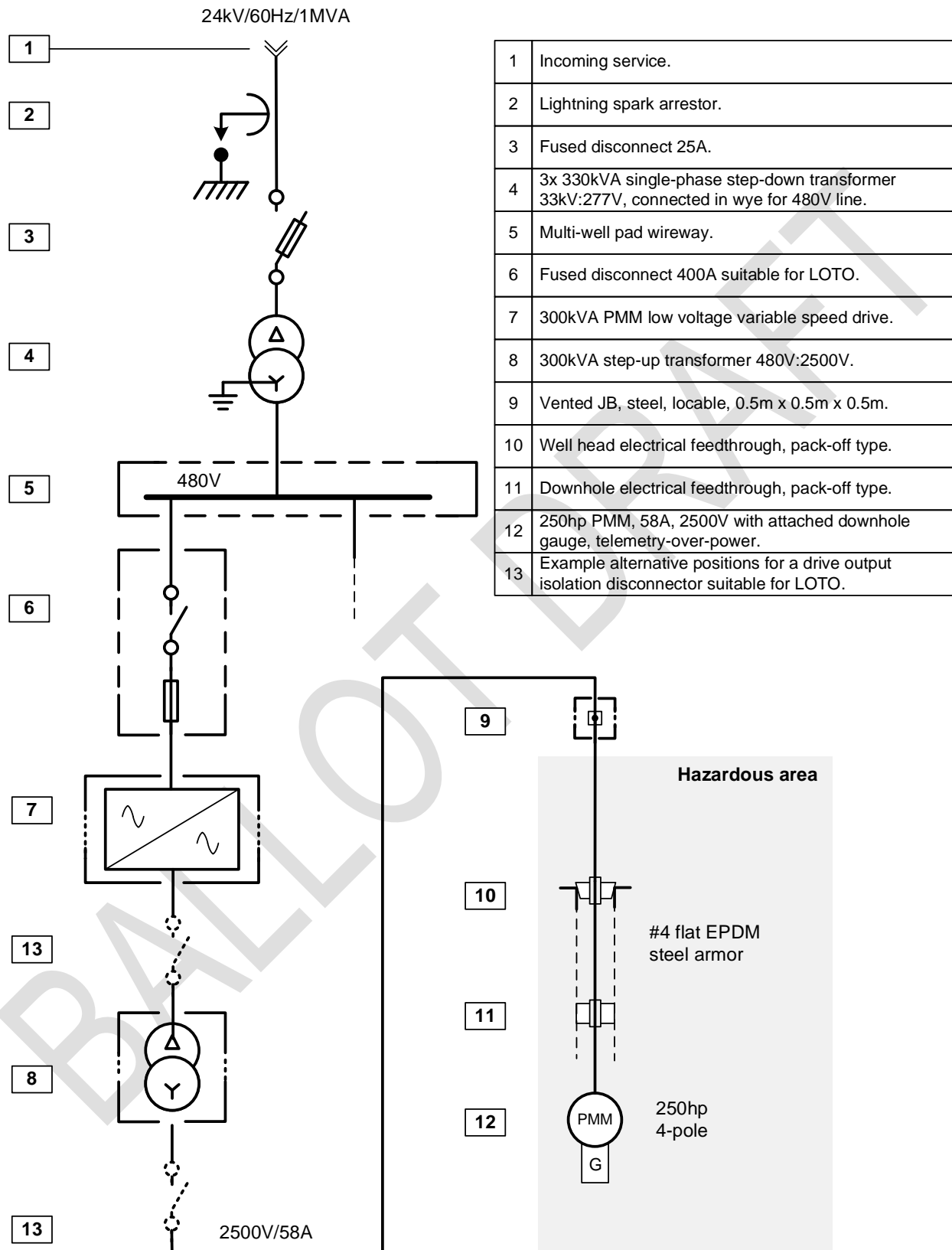


Figure 11—Conventional ESP electrical power system one-line diagram.

### **14.3 General recommendations**

The following are recommendations to mitigate the risks an attendant or technician may experience during any cable operations:

- a) At least one additional person to the task qualified technician performing a given operation is to be present to witness all operations. If the technician requires first aid or other medical assistance, this additional person will seek out help as required.
- b) Following the job safety briefing (section 7) and suppliers' work instructions, confirm all risks are identified and mitigating actions are in place. These will include:
  - 1) Wear PPE appropriate to the hazards identified. Refer to Annex C.
  - 2) Verify that all electrical and mechanical LOTO devices are in place and in the safe position (refer to the appropriate section of this document for the task being performed).
  - 3) Ensure no SIMOPS will take place when working with the conductors.
    - i. The individual performing the work is to personally notify the rig operator and confirm that there will be no simultaneous operations.
  - 4) Always assume the cable is potentially energized if it is connected to the motor and the motor is below the well head.
  - 5) Verify absence of voltage prior to any contact of a conductor. If voltage is detected, stop work until motor rotation has ceased. Determine the cause of rotation and consider any actions that will prevent recurrence.
    - i. Testing for absence of voltage should be performed per a live – test – live methodology (test on a known live conductor, then test on the conductor in question, and, if no voltage is indicated, test again on the known conductor to confirm the test device is still working properly).
    - ii. Measurements should be performed on between all three phases and each phase to ground.

WARNING—Proving that the power cable is de-energized is required not only to minimize potential for electrical shock hazards but also, in the hazardous area, to mitigate potential for sparks to be generated during any disconnection of the cable ends such as from a shorting device or penetrator.
    - iii. When performing any of these operations during RIH or POOH, it is recommended that:
  - 6) Tubing should be landed in the slips and the brake handle locked down
  - 7) Cable spooler controls should be rendered inactive, and the brake engaged.
  - 8) Any downhole prevention of rotation device be activated.
- c) Perform all cuts and splices outside the hazardous area whenever possible. When not possible:
  - 1) Continuous monitoring for flammable gas shall be in place.
  - 2) A hot-work permit is required.
- d) Insulated hand tools (such as cable cutter, wire strippers, pliers, and wrenches) are recommended instead of non-insulated hand tools.
- e) Continuous monitoring of the cable ends for any EMF (if ends are open) or current (if ends are shorted together) is recommended for detection of unplanned motor rotation.
- f) Grounding, shorting, and/or isolating the cable ends as applicable per the given step to be performed as per the equipment supplier instructions. Shorting blocks that securely grip the individual conductors should be used, not conductors twisted together.
- g) When shorting the phase conductors together, sufficient insulated conductor length should be left exposed to enable use of an ammeter to measure conductor current.

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- h) When isolating the phase conductors, prepare the cable ends to prevent incidental contact. This can be achieved in multiple ways such as locating the cable ends within an isolation device (a temporary JB) and/or by insulating the cable ends with properly rated electrical tape.

## 14.4 Spooler operations

The following are recommendations in addition to section 14.3.

For spooler operations, it is recommended that at a minimum the ESP power cable reel and trailer or winch unit be always grounded. Depending on the operation being performed, additional grounding may be required (refer to equipment supplier instructions). Refer to Annex D on grounding, which also covers requirements for an equipotential bonding zone when working with shorted and grounded cable ends. Figure 12 illustrates insulated and shorted ESP power cable reels.

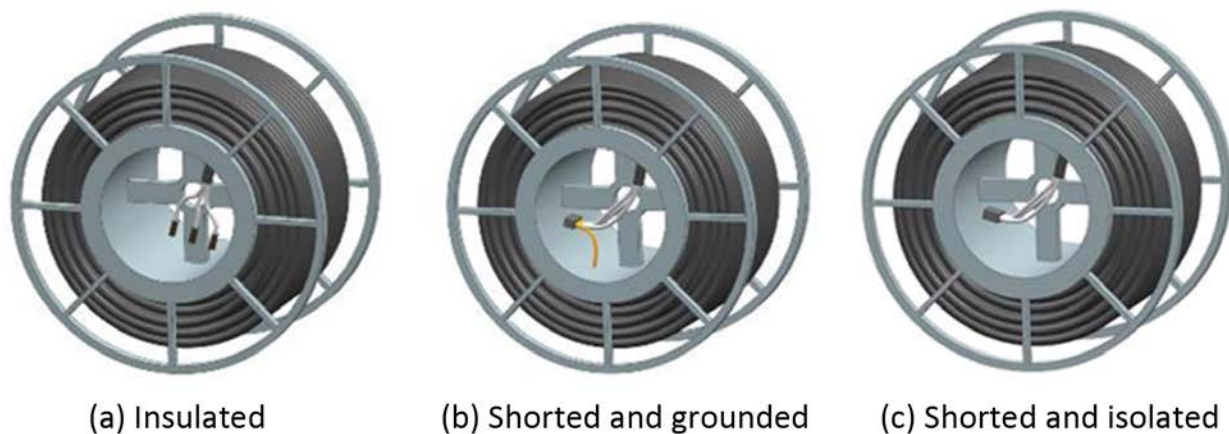


Figure 12—Cable terminations in reel.

When operations such as electrical checks are not being performed, the cable ends in the reel should be isolated from any incidental contact. When possible, continuous monitoring of the ESP power cable should be in place and utilized to alert personnel to the presence of voltage and or current. If detected, stop work until the hazard is mitigated. See also section Annex B on instrumentation.

## 14.5 Changing out cable reel

The changing out of a reel that has reached its cable length capacity limit can pose a potential risk to personnel for electric hazard from unplanned motor shaft rotation.

During RIH, the cable would be spliced to the second reel's cable and the cable termination transferred to the second reel (see 14.7).

During POOH the cable would be cut and moved over to the empty reel (see 14.6).

## 14.6 Cable Cutting

The following are recommendations in addition to section 14.3.

Cutting of the ESP power cable is a common field practice that is required for various situations such as when repairing, lengthening, or terminating this cable. With the advent of PMMs and the possibility of unplanned motor rotation, this has become one of the more potentially dangerous field operations if not

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conducted properly. For example, even if the ESP power cable ends are shorted and grounded there may be significant voltage at the location along the conductor where the cut is to be made if the motor were to rotate. In addition, cutting the cable would then remove the short from the cable allowing significantly more voltage to be generated.

Prior to making any cut of the ESP power cable:

- a) Confirm that the motor is not generating EMF. Non-contact voltage detectors are not necessarily able to detect voltage when placed outside the cable armor (see B.5). Due to this, voltage detection should be performed at the cable ends with an appropriately rated voltage detector. If leads are shorted, current detection should be performed using an appropriate ammeter.
- b) If a surface ESP power cable repair is required, ensure LOTO is performed at the supply, and at the JB as appropriate.
- c) Utilize an insulated cable cutting tool. (This may not add to safety in wet conditions.)
- d) If a remote cable cutting tool is utilized, ensure it is rated for the application and voltage potential.

Any conductive protection such as cable armor or tubing encapsulation should be grounded on both sides of the proposed cut location. This will ensure that the exposed protection does not become inadvertently energized during the cutting process. For most purposes when cutting a cable, the ground is already present as one side of the cable is in the well and the other side is on the grounded reel.

Once the cable has been cut, it is important to immediately prepare the cable ends and either reapply the short and ground to all three cable conductors or to isolate and insulate as per supplier recommendations and depending on the subsequent steps to be performed. Regardless of the method used to prepare the ends, the conductors should be isolated from incidental contact and remain inside the access barrier.

## **14.7 Splicing**

The following are recommendations in addition to section 14.3.

Splicing is a skilled operation which normally requires manual handling of the phase conductors to achieve a satisfactory (reliable) result. Where possible, splices are made prior to arrival at the wellsite. Splicing may include:

- a) The MLE to the main run of ESP power cable.
- b) Transposition splices sometimes used on long flat cable.
- c) Repairs to ESP power cable damage (such as if caught in the rig slips).
- d) Field extension of cable length in deep wells.
- e) Attachment of certain types of electrical cable feedthrough, at the wellhead or at a downhole packer.
- f) Each equipment supplier will have their own specific splicing instructions for the ESP power cable to be used. Any concerns or questions of these procedures should be evaluated in job planning (section 5).

Primary Recommendations:

- g) A grounded equipotential bonding zone should be established on the motor side of the cable by shorting and locally grounding all the ESP power cable conductors, cable armor and splicing table (if conductive).
- h) At no time should there be only one or two phases grounded or shorted. Either all three or none should be grounded and shorted per the specific operation being performed. Refer to Annex D for grounding.
- i) Verify that cable conductor insulation of the system has not been compromised prior to performing a cable cut or other further step with the splicing operation. If damage is detected, do not proceed with the splicing operation until addressed.

Secondary splicing recommendations that can be considered include:



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- j) If the splicing table is conductive, taking additional steps to isolate the technician from contact with it such as putting an insulative mat over the table.
- k) Isolating the technician from ground by having them either wear dielectric boots or stand on a dielectric mat.

## 14.8 Electrical cable feedthroughs

The following are recommendations in addition to section 14.3.

Electrical cable feedthroughs are used to bring the ESP power cable through the wellhead or downhole packer while also providing a fluid (gas and/or liquid) seal. The feedthroughs fall into two broad categories:

- Uninterrupted cable
- Interrupted cable (using one or two connectors or an integral JB termination)

Preparation of cable conductors for splicing or for making terminations requires access to exposed conductors. This is one of the hazards with PMM deployments due to the potential for shock from unplanned motor rotation. Figure 13 illustrates five possible terminating examples.

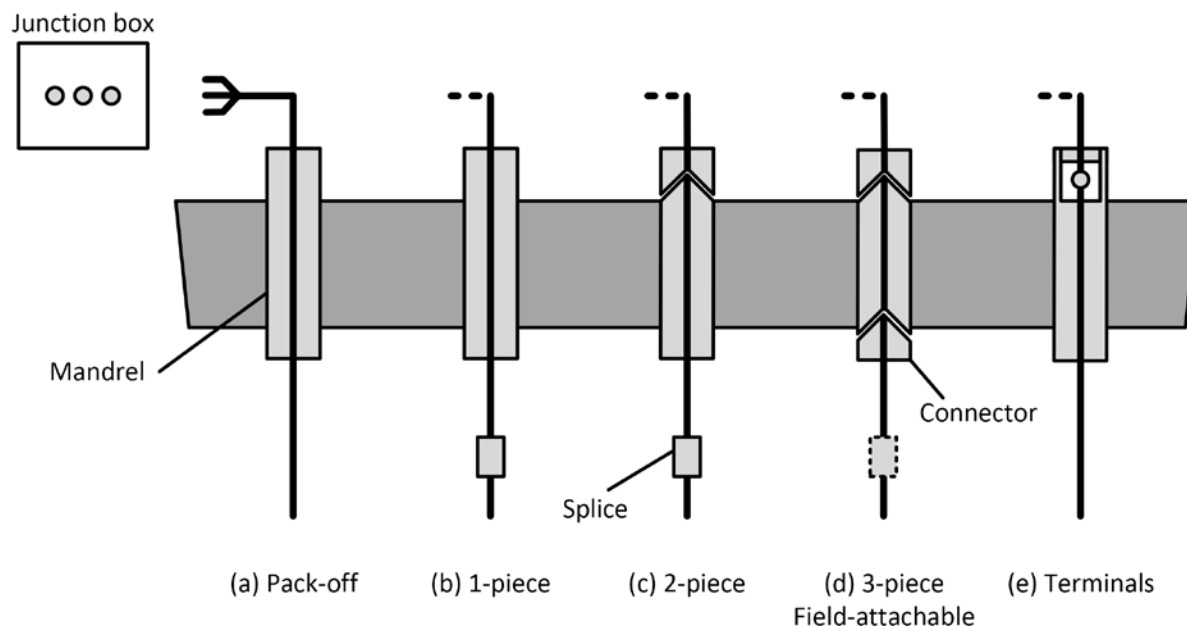


Figure 13—Feedthrough classification.

Use of API RP 500 and API RP 505 Class 1, Division 1/2 (C1D1/2) type devices (connection boxes, caps, etc.) is to be aligned per job safety plans (section 5), the job safety briefing (section 7.2) and the general recommendations for cable operations (section 14.1) as they pertain to the hazardous area. Work performed should also be aligned.

### 14.8.1 Feedthroughs with continuous cable

Figure 13(a): Use of a pack-off feedthrough to exit the wellhead allows the end user to avoid splices.

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Completions that allow use of pack-offs are generally depleted with high water cut and thus have no flow to surface (such as geothermal wells). Fortunately, these types of wells are also where the efficiency improvement with a PMM are most advantageous. Pack-offs are not recommended for high gas-liquid ratio (GLR) wells and those with high H<sub>2</sub>S and/or CO<sub>2</sub> gases.

The cable preparation typically only requires removing the cable armor and jacket at the wellhead exit and using compression energized elastomeric seals on the insulated conductor singles. Some pack-offs use round cable and only require armor removal, sealing around the jacket. This method of wellhead exit allows for the conductor splice to be eliminated along with that electrical hazard. Pack-off systems have lower pressure ratings, generally 1500 psi working pressure compared to 5000 psi for a standard penetrator. There is a potential for slow gas permeation, so a vented JB is also required.

Figure 13(b): A 1-piece penetrator feedthrough has a length of cable sealed into a mandrel, with the upper and lower extensions respectively termed the upper and lower pigtails. The lower pigtail is spliced to the ESP power cable. Typically, the mandrel shall be loaded into the wellhead from above so that the splice shall be done at the tubing (unless an extra-long pigtail is used). With a bottom-loaded mandrel, the splice can be done [safely] in the non-hazardous area. Typically, the upper pigtail will be long enough to reach the JB. If not, an extension shall be spliced on. It is recommended that the upper pigtail be long enough to extend to the non-hazardous area.

#### **14.8.2 Feedthroughs with interrupted cable**

Penetrator feedthroughs with interrupted cable take on many forms. They typically have a higher-pressure rating and are gas tight compared to pack-offs.

Figure 13(c): Two-piece penetrators use a plug-in connector above the well head and a pre-assembled lower pigtail and mandrel. If the mandrel type is inserted from below the well head, then the lower pigtail and ESP power cable can be spliced in the non-hazardous area without using a long pigtail.

Figure 13(d): Three-piece (field-attachable) penetrators use plug in connectors above and below the penetrator mandrel. The upper pigtail can be pre-assembled to its connector. The ESP power cable is typically field assembled to the lower connector, in the non-hazardous area. Alternatively, the lower connector can be pre-assembled to a pigtail, and the pigtail spliced to the ESP power cable, in the non-hazardous area.

Figure 13(e): Terminated penetrators pass the ESP power cable conductors up through the mandrel and terminate the cable ends in an integral gas-tight JB commonly known as a conduit box. The upper pigtail is subsequently attached into the conduit box. A representative example is shown in Figure 16. A splice is not required but could be used below the wellhead to reduce manual working on the penetrator.

When the upper pigtail is connected or disconnected at the integral JB, the conductors at the other end shall be isolated to avoid the risk of sparks.

Penetrators using an upper connector usually have a temporary cap to protect the contacts. If the connector and its pigtail or the cap short the contacts, then there is the possibility of sparks at the well-head if the motor is rotating when the joint is made or disconnected. As such, these types of connections should be configured to meet explosion-proof/flame-proof specifications to prevent an internal spark from reaching the surrounding atmosphere. Alternatively, a connector and temporary pigtail that shorts and grounds or insulates outside the hazardous area may be used. The short and ground is removed prior to making or breaking the connector.

The recommended practice for feedthrough mandrel removal without cutting cable in the hazardous area starts with the reader having read section 14.8.4, where the surface mandrel has been capped and the well crew is removing the wellhead.

- a) The protective cap shall remain in place while within the hazardous area.
- b) Where possible, the feedthrough mandrel is to be fed through the cable sheave to perform cable cutting procedures in a non-hazard area.

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- c) If the feed-thru mandrel is unable to pass through the cable sheave, then feed the cable to the non-hazardous area for the purpose of cutting.
- d) Prior to cutting the cable, confirm the absence of voltage. If voltage is present, do not continue until steps are taken to determine the cause of voltage and to eliminate it. If elimination of voltage is not possible or infeasible, then the shock and arc flash mitigation methods as determined in the job safety plan should be followed. The qualified person performing the task is to take the appropriate measures or steps to ensure an electrically safe working condition prior to cutting the cable in the non-hazardous area. This can involve many different things to do during this troubleshooting phase.
- e) Perform the cable cutting procedure and apply one of the recommended (shorting / grounding) or (isolate / insulate) procedures and feed the cable through the cable sheave to the reel.

Feedthrough mandrel removal with the cutting of cable in the hazardous area necessitates Hot Work and is required to have continuous gas monitoring and voltage detection monitoring. Shock and arc flash mitigation methods as determined in the job safety plan should be followed.

- a) Prior to performing this operation, consider and implement all required mitigations for hot work activity as applicable.
- b) Remove the feedthrough mandrel from the tubing hanger and remove the protective cap
- c) Using contact-less meter with display, test the presence of voltage. For voltages over 1000V, non-contact test instruments, rated for the anticipated voltage, can be used to verify the absence of voltage at the point of work.
- d) Do not continue if hazardous voltage is present. Cease operations, secure the protective cap, and investigate the cause of voltage. Only when the voltage is eliminated may work continue. The qualified person performing the task is to take the appropriate measures to ensure an electrically safe working condition prior to cutting the cable in the hazardous area.
- e) Perform the Hot Work cable cutting procedure and apply one of the recommended (shorting / grounding) or (isolate / insulate) procedures and feed the cable through the cable sheave.

#### **14.8.3 Procedure guidelines**

The many penetrator designs that are available do not allow specific guidance to be given. It is recommended that penetrator suppliers provide PMM-safe assembly procedures, considering:

- a) The recommendations in this document for shorting and grounding to maintain a locally grounded equipotential bonding zone, and/or electrical isolation of the conductors. Refer to Annex D for additional considerations.
- b) An operator-approved flammable gas detector should be used if there is the possibility of flammable gas in the work area.
- c) Avoidance of sparks caused by making and breaking of conductors and ground leads in the hazardous area.
- d) Removal of temporary protective caps can expose personnel to live conductors or create sparks when removed.
- e) Whether it is required to use a prevention of rotation device in the well.
- f) Space limitations in any JB, which may make it difficult to make connections without inadvertent handling of live conductors.
- g) When grounding, only all three phases or no phases should be grounded depending on the operation being performed. At no time should only one or two phases be grounded or shorted (see section 4.2).
- h) Listing requirements for PPE, tooling, and approved instruments.

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One practice to mitigate the issue of assembling within the hazardous area is to pre-cut the ESP power cable to length and pre-attach the penetrator, then deliver to the well site on the spooler. In the final stage of RIH, a short tubing joint (pup joint) is used to space-out the tubing length to match the cable / penetrator length. This method minimizes electrical working on the cable at the wellhead. The penetrator mandrel shall be installed from below the hanger.

Installers should follow the suppliers' PMM-safe procedures. Any concerns or variations should be agreed with the operator and reviewed per section 5.

Operators may select penetrators based on assessment of the above procedures.

#### 14.8.4 Surface Pigtail Disconnect

Once the authorized electrician or service technician has performed LOTO on all surface equipment and verified using live-dead-live process, the surface pigtail can be removed to mitigate against sparks before well crews arrive. The operator of the well is to close the wellhead casing and tubing valves. The service technician should test for voltage at the vented JB. If voltage is present, do not continue onward with feedthrough procedures; steps should be taken to determine the cause of voltage and to eliminate the voltage present at the vented JB. If elimination of voltage is not possible or infeasible, then the shock and arc flash mitigation methods as determined in the job safety plan should be followed.

**NOTE** Voltage does not diminish like a gaseous vapor does by dispersion; it is a time dependent decay related to the pump rotation slowing to a full stop. If the voltage does not diminish then there is a completion source (diverter valve, sliding sleeve, other etc.) resulting in steady fluid flow to the pump which drives the PMM in a generative manner.

Typical steps to disconnect the surface pigtail include:

- a) Disconnect terminals from vent box, isolate and insulate the conductors individually. Remove the surface pigtail (Figure 14) from the wellhead feed-thru mandrel and install a protective cap on surface pigtail.

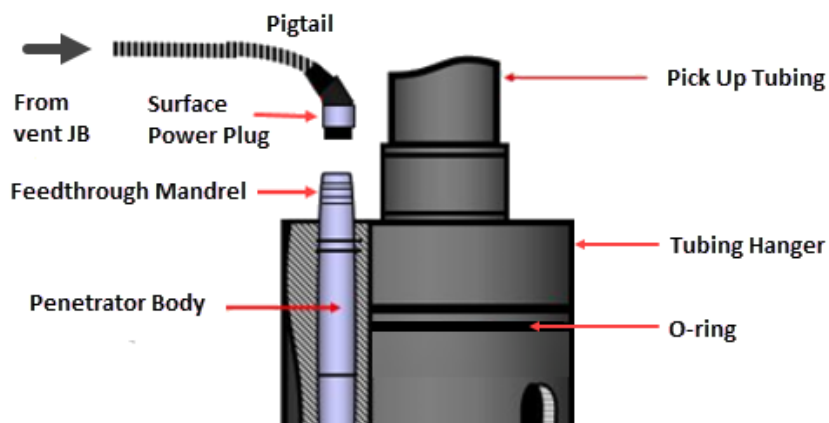


Figure 14—Surface pig tail.

- b) A non-shortng protective cap is to be installed on the wellhead feed-thru mandrel. The protective cap should be of design that allows the wellhead bonnet or top flange to pass over and through the cable sheave. Figure 15 shows an example protective cap.

Caps, penetrator feedthroughs, and wellheads come in many designs and may differ from well to well, so it is important to select caps in alignment with the job safety planning and job safety

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briefing with respected to the hazardous area alignment. Caps which isolate and insulate are recommended.

**WARNING**—While caps that short and ground above the wellhead can be found in industry use, they are not recommended for use with PMM because the cable is still exposed to safety risk below the wellhead.

- c) Having safely removed the surface pig tail and capped the surface mandrel, the well service crew may now perform wellhead removal following the well control standard operating procedure, however the crew should proceed with awareness that a PMM is in the well.

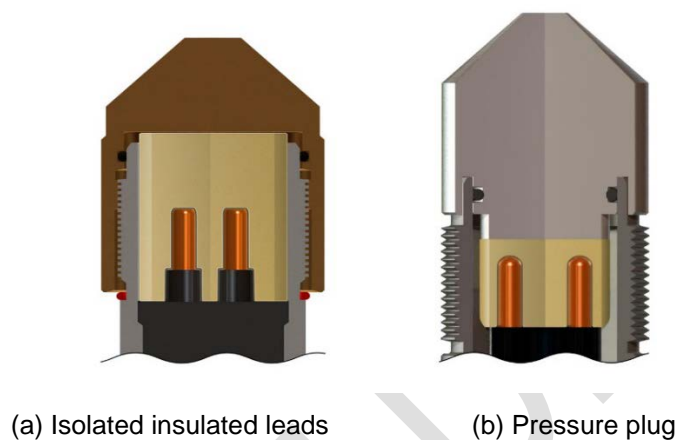


Figure 15—Protective cap cut-aways.

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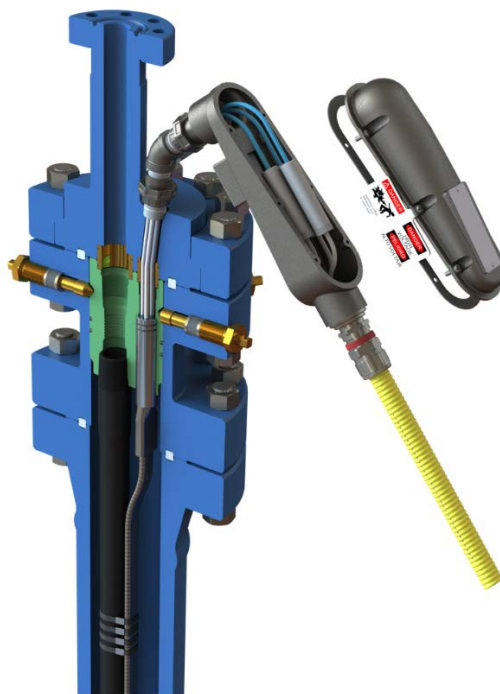


Figure 16—Feedthrough with enclosed terminals.

## **Annex A. (normative) Training and task qualification**

### **A.1 General**

This section provides recommendations for training of personnel who will work at wells where PMMs are installed.

The recommended training shall be given consistent with national and local regulatory requirements.

### **A.2 General awareness**

The operator shall provide written information to, and instruct, all persons who are not task qualified to work on PMM installations, for their own safety and the safety of others:

- a) Understand that the electrical system can be live at any time even with drive supply removed or site power cut, due to the installation of a downhole generator.
- b) Do not cross access barriers.
- c) Do not access any electrical equipment unless task qualified.
- d) Do not commence any simultaneous operations.  
EXAMPLE – Well control/pumping fluid down the well while checking the electrical integrity of the ESP system.
- e) Observe all signs.
- f) Well control, other alarms, accidents and first actions to take.

This instruction shall be acknowledged by signature and recorded.

EXAMPLE – supervisors, tool pushers, rig operators, spooler operators, ESP technicians.

### **A.3 Task qualification**

Task-qualified persons are competent to perform all, or part of the electrical work needed during the PMM installation life cycle.

**WARNING**—Thorough training is required to perform electrical tasks on PMM electrical systems due to the special nature of voltage being developed by unexpected motor rotation. The motor may be out of sight downhole or integrated into surface equipment.

All personnel exposed to the risk of electrical shock and arc flash shall have received training that allows them to identify and properly mitigate all risks that may be encountered while performing an assigned task. This training shall require that the individual demonstrate the ability to identify all risks and safely perform the task. In other words, not only receive the training but also demonstrate competence to support that the individual is “qualified to safely perform the task”. This is “task qualification”.

Training for task qualification should include:

- a) Supervised training.
- b) Supervised and demonstrated field practice.
- c) Issue of a certificate of training identifying the person, training body, date, period of validity and the approved tasks to which the training applies.

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It is recommended to re-certify the task-qualified person annually, for example by inspection of work in the field.

Certificates meeting the requirements of this document may be issued by PMM suppliers, operators, training organizations and by suppliers of specialist equipment for its safe installation and use.

Task-qualification is limited to the scope of work the certification covers.

Electricians certified for installation work under national and local regulations are not automatically task-qualified for working on PMM pumping systems.

## **A.4 Recommendations for training**

### **A.4.1 Prerequisites**

The following items will ordinarily have been received by installation and maintenance personnel trained in conventional induction motor-based ESP installations:

- a) Basic understanding of the operations conducted, and equipment used at a well site that employs electric submersible pumping.
- b) Well control principles.
- c) Wellsite procedures, Job Safety Plans, energized electrical work permits and stop work authority.
- d) Basic understanding of voltage and current.
- e) Basic understanding of grounding and equipotential bonding zones.
- f) Understanding that electrical testing will expose the worker to risk of shock and the need for safe practice.
- g) Hazardous voltage and approach boundaries.
- h) Effects of wet weather on electrical risks.
- i) Selection, maintenance and use of electrical PPE.
- j) First aid including safely rescuing a victim of electric shock or arc flash.
- k) Selection and correct use of conventional instruments, typically hand-held, for voltage, current, resistance and insulation testing and troubleshooting. This will include use of high-voltage probes and the need to discharge cables after insulation test. See section Annex B.
- l) Live-test-live absence of voltage methodology.
- m) Use of monitoring systems for automatic detection of unplanned motor rotation.
- n) Work skills for the tasks the person is being trained for, for example RIH, cable splicing, cable testing, transformer setting, VSD commissioning, accessing live equipment for measurements.
- o) LOTO methodology.
- p) Isolation of VSDs.
- q) Field experience gained under supervision (on the job training).

### **A.4.2 PMM training**

The following items are additionally required for electrical workers on PMM installations. The selection of topics will depend on the scope of work to be certified for a particular person:

- a) Basic characteristics of PMMs, motor as generator, EMF.
- b) Two sources of electrical power to surface equipment.
- c) Unplanned motor rotation – causes and effects.
- d) Shorting and grounding to eliminate voltage at the point of working.
- e) Hazardous voltage generated at low shaft speed.



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- f) Selection and use of instruments and accessories for PMM related electrical measurements (see section Annex B).
- g) Detection of energized equipment and conductors during unplanned motor rotation.
- h) Additional PPE requirements for arc flash hazards.
- i) Well control basics relating to PMMs.
- j) Avoiding or preventing sparks in the hazardous area caused by downhole generation.
- k) Cable-related operations including measurements at the spooler, splicing and penetrator makeup.
- l) Training as required for any special tasks to be performed, such as
- m) safe assembly of specific penetrators (this may be performed as a service by penetrator suppliers)
- n) safe deployment of different pumping technologies.
- o) Recommendations of this document for Arrival at location, RIH, POOH, and maintenance.

## **A.5 Trainers**

Persons giving PMM training schools should:

- a) have a thorough understanding of the then current version of this RP
- b) be practically experienced in their training topics
- c) be able to prepare written practical operator and supplier procedures consistent with this RP

## **A.6 Terminology**

National codes of safe practices and training requirements for electrical workers may be based in the USA on NFPA 70e and in Europe on IEC/EN 50110 and its 34 national annexes. Many other countries have standards closely aligned with these. Table A.1 provides a comparison of terms in this document and in widely used national standards.

**NOTE** Persons in the electrical standards of Table A.1 are not necessarily task qualified as defined by this document

Table A.1—Approximate comparison of terms.

<b>This document</b>	<b>NFPA 70e</b>	<b>IEC 50110</b>
All persons	Non-qualified	Ordinary person
Task-qualified	Qualified person	Instructed person
Trainer	-	Skilled person

## **Annex B. (normative) Selection and use of electrical instrumentation**

### **B.1 General**

All measurements made with electrical instrumentation should be made by task qualified persons working within an access barrier and with no SIMOPs.

Instrumentation to be used should be reviewed as part of job planning. In PMM systems, many hand-held instruments routinely carried as part of the field personnel's toolkit are unsuitable. This section considers the requirements for PMM systems.

CAUTION—No work on the electrical system should be done if there is voltage or current present.

CAUTION—A manual measurement of zero voltage or current before handling a conductor does not guarantee that there will be no voltage or current when the conductor is handled, because unplanned motor rotation can start at any time.

### **B.2 General characteristics and requirements**

PMMs generate internal voltage (EMF) during any rotation, at a level and frequency which is directly proportional to the rotation speed. Conventional submersible pumps are typically operated up to 4500 rpm. Some types of pumps can be run at much higher speeds and hence frequencies. Positive displacement pumps such as progressing cavity type will normally run at a few hundred rpm with relatively low frequencies.

NOTE 1 Readily available conventional handheld meters are suitable for making measurements at the VSD supply but do not necessarily meet the requirements for instrumentation to be used on the PMM systems.

NOTE 2 Common industry practice is to express rotation speed in Hz, with the understanding that 60 Hz is 3600 rpm synchronous speed. Unlike IMs, PMMs are frequently manufactured with 4 or more poles, in which case the electrical frequency of the motor is a multiple of its shaft rotation frequency. In this section on instrumentation, frequencies are electrical unless otherwise stated.

EXAMPLE 1 A PMM has an EMF of 1800 V at 3600 rpm. Its nameplate voltage is 2000 V at 3600 rpm, corresponding to the voltage necessary to drive nameplate current into the motor against the EMF (sometimes referred to as back-EMF for this reason). The motor is running at nameplate conditions, driving the pump, when it is stopped. Back spin rapidly commences as the fluid in the tubing drains and the pump now drives the motor, as a generator. If the cable phases are open, its voltage at surface will be the EMF, reducing as the speed reduces (see Figure I.5a).

EXAMPLE 2 – The same PMM will generate EMF of 15 V at 30 rpm. The frequency of a 2-pole PMM will be 1 Hz at 30rpm. These frequencies will increase with higher pole-count motors.

When sizing the motor, it is often preferred to run at a high voltage and a low current. Motor nameplate voltage is commonly 2000 – 4000 V. During initial back spin, some pumps will drive the motor significantly higher than the normal running speed resulting in increased EMF (which for high nameplate voltage can stress the electrical system insulation).

When the ESP power cable phase conductors are shorted together, the EMF generated from motor rotation will force current to flow in the cable conductors, at the same frequency as the voltage. Unlike voltage, current amplitude will reach a limit as speed increases (see Figure I.3). The limiting current exceeds the nameplate current. However, current flow results in braking torque being applied by the motor to the pump, which will limit the speed, and hence EMF, such that the limiting current is often not reached.

### **B.3 Instrumentation limitations**

Many conventional meters will only be able to measure AC voltage or current at frequencies above 30Hz for AC measurements and below 1000 V. They may make indications at very low frequency, using DC

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measurements. These devices may have a significant inoperable region where they are unable to measure voltage or current with either AC or DC measurement techniques and so not be able to meet the minimum requirements.

To meet the requirements at low frequency it may be necessary to select and use instrumentation outside its supplier's published specification, after testing it for satisfactory operation.

**CAUTION 1**—Instrumentation suppliers sometimes make design and manufacturing changes that do not affect the published specification and so do not change the product part number or documentation. Such changes can however change behavior outside of its published specification. Consequently, each newly purchased or repaired instrument should be qualified at the full range of expected usage prior to being placed into service.

**CAUTION 2**—Some applications may have some background “noise” that may cause the measurement device to give false positives for voltage. It is important to understand the sensitivity of the measurement device and what may cause it to give a false reading. Each reading shall be repeated prior to determination. When in doubt an alternative meter or a proving device should be used.

## **B.4 Separation**

Measurement devices that do not require manual intervention, or which maintain a safe distance between technician and the point of measurement, are recommended. This can also reduce the level of electrical PPE required. However, the instrument should still be rated to the potential voltages generated with a PMM.

EXAMPLE 1 – Instruments that include a remote display.

EXAMPLE 2 – Instruments that use an extended probe mounted on a hot stick or similar device.

EXAMPLE 3 – Using a non-contact voltage meter that senses voltage at a given point.

EXAMPLE 4 – Instruments that are permanently connected and can be read from a distance.

## **B.5 Voltage detection**

It is recommended that the voltage measurement device:

- a) be able to detect voltages down to 25 V and down to 1 Hz.
- b) be capable of measuring at the highest expected voltage and frequency. This should include consideration of possible maximum EMF from unplanned rotation.
- c) be able to measure and recognize distorted voltage waveforms that have a peak voltage higher and a rms voltage lower than hazardous voltage.

**CAUTION**—Care should be taken when selecting and using non-contact devices. These may be affected by background electric /magnetic fields. They require physical separation of conductors to avoid field cancellation of the measured signal. Non-contact devices are usually intended for 47 – 63 Hz utility frequency measurement. Some may deliberately filter out anything beyond this range. In addition, non-contact voltage detectors are not necessarily able to detect voltage when placed outside the cable armor.

**CAUTION**—Even if the three phase conductors are shorted together and grounded at the point of working, there is potential for phase to phase or phase to ground voltage elsewhere in the circuit. Before creating a new point of work by moving the grounding or shorting device, first confirm the motor is not generating EMF. For example, shorting and grounding the cable ends in the spooler does not ensure there is no voltage at the point where the cable is to be cut or spliced. The point of working has moved to the cutting or splicing operation, where the short and ground would need to be applied on the motor side of the operation. Other examples include a crushed cable during installation or an MLE/cable burn during a pull. These examples illustrate the need for measurement to confirm no voltage is present before contacting any conductor.

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Voltage probes are typically used as part of a divider circuit to permit the use of low voltage instruments such as typical hand-held meters and field oscilloscopes. Voltage probes should be internally impedance limited so that they are safe at the end to be connected to the readout device, even if they become disconnected. Impedance limited probes should be used for both contacts to permit safe phase to phase (ungrounded) measurements.

**WARNING**—Do not use single-ended probes. They are intended for use from phase to ground. However, they will bring hazardous voltage direct to the meter terminals if used phase to phase.

**WARNING**—Do not use probes which are not impedance limited. This type of probe will bring hazardous voltage direct to the possibly hand-held instrument.

### **B.5.1 Application**

Voltage should always be measured between every pair of phase conductor and every phase conductor to ground.

**NOTE** This addresses the possibility of an open or shorted conductor that would give a zero reading.

There are two typical methods for voltage detection:

- a) Intermittent [manual] monitoring: typically used prior to making any direct contact with the cable or conductors. For this method, the instrument should follow the test – measure – test methodology to ensure the absence of voltage is reliably detected.
- b) Continuous monitoring: typically, a device permanently mounted in the cable reel to detect voltage at the cable ends.

**NOTE** It is recommended to use continuous (permanently connected) monitoring of the cable for the purpose of detecting motor rotation. This device will ideally be able to make cable electrical checks without manual intervention by the technician.

Any monitoring device connection shall be made securely to prevent loss of continuity that might result in the inability to detect rotation.

## **B.6 Current detection**

It is recommended that the current measurement device:

- a) use a flux sensor non-contact clamp.
- b) be capable of detection of current down to 100 mA and down to 1 Hz.
- c) be capable of measuring at the highest expected current and electrical frequency. A guideline for conventional pumps is 2.5 times motor nameplate current and 200 Hz. At the VSD output use 2.5 times drive nameplate current.
- d) be able to measure and recognize current waveforms that may not be fully sinusoidal.

A transformer clamp is not suitable as it will not provide a measurable current at low frequency.

Sufficient space shall be included on the non-armored conductors to secure the current detector prior to the initial application of a short.

### **B.6.1 Application**

For current to flow in a phase conductor the conductor shall be part of a closed phase circuit. Current should always be measured on at least two-phase conductors, in case one conductor is open circuit.

There are two typical methods for current detection:

- a) Intermittent[manual] monitoring: typically used prior to making any direct contact with the cable or conductors. For this method, the instrument should follow the test – measure – test methodology to ensure the absence of current is reliably detected.

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- b) Continuous monitoring: typically, a device permanently mounted in the cable reel to detect current at the shorted cable ends. Continuous monitoring devices should also detect loss of conductor continuity.

CAUTION—Even if the three phase conductors are shorted together and grounded at the point of working, there is potential for phase to phase or phase to ground voltage elsewhere in the circuit. Before creating a new point of work by moving the grounding or shorting device, first confirm the motor is not generating EMF. For example, shorting and grounding the cable ends in the spooler does not ensure there is no voltage at the point where the cable is to be cut or spliced. The point of working has moved to the cutting or splicing operation, where the short and ground would need to be applied on the motor side of the operation. Other examples include a crushed cable during installation or an MLE/cable burn during a pull. These examples illustrate the need for measurement to confirm no voltage is present before contacting any conductor.

It is recommended to use continuous [permanently connected] monitoring of the cable for the purpose of detecting motor rotation. This device will ideally be able to make cable electrical checks without manual intervention by the technician. Any current monitoring device connection shall be made securely to prevent loss of continuity that might result in the inability to detect rotation.

In some cases, it may be necessary to transition from closed to open conductors and vice versa for measurement purposes (depending on the capability of the monitoring device to limit the need for this change). In this situation, the BHA should be confirmed to not be rotating, any applicable LOTO performed, and appropriate PPE used while making this change.

CAUTION—Sufficient space shall be included on the non-armored ESP power cable phase conductors to be able to secure the current detector prior to the initial application of a short.

## **B.7 Other measurements**

### **B.7.1 Resistance and Insulation**

Cable electrical resistance measurement and insulation test is typically performed several times during RIH on the end of the ESP power cable.

DANGER – Insulation test applies a high voltage between conductors and ground, which charges the ESP power cable. The cable is then a hazardous energy source that shall be discharged immediately after the test and before any other work proceeds. Discharge should be through the test instrument so that disconnection does not expose a charged cable.

There are two methods for resistance measurement and insulation test:

- 1) Readily available instrumentation: Instrumentation is employed after verifying there is no motor rotation using current or voltage measurement as described above.

The phase conductors are manually disconnected and exposed to enable phase to phase and phase to ground measurements.

DANGER— Electrical PPE shall be worn during this testing as unplanned motor rotation may occur at any time. It is likely the test instrument will be damaged.

- 2) Special purpose instrumentation: Instrumentation with remote read-out that is permanently connected to the cable end and does not require manual intervention on the phase conductors. This can be part of a continuous monitoring system.

### **B.7.2 Time-domain reflectometry**

Time domain reflectometers (TDRs) are sometimes used to locate the position of an electrical fault, for example below the well head, at the motor or somewhere between. This can be an aid to planning safe POOH.

See B.7.1(1) for the use of low voltage instrumentation.

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## **B.8 Continuous monitoring**

### **B.8.1 Detection of unplanned motor rotation**

Voltage or current measurement can be used to detect unplanned motor rotation.

It is recommended to use continuous monitoring of the cable end for the purpose of detecting and signaling motor rotation.

### **B.8.2 Current based**

A current monitoring device connection in the hazardous area or vented JB shall be mounted securely to avoid incidental bridging of conductors that might result in a spark.

All three phases of the cable shall be shorted together and grounded at the measurement point to create a grounded equipotential bonding zone, typically at the cable end at the spooler or the motor side of the cable for a splice.

When rotation occurs, no voltage is generated between phases or phases to ground at the monitoring device. Current flows in the phase conductors.

Check that the phase-to-phase resistance values are as expected for the motor and ESP power cable. If the insulation integrity or conductor continuity is damaged sufficiently that no motor-related current would flow through at least one phase, this method of monitoring will ensure that there is no voltage at the measurement point, typically the point of working. However, indication of no rotation may be unreliable.

### **B.8.3 Voltage based**

If a means of shorting or safe disconnection is not provided when accessing power cable connections (such as in a JB or other cable conductor connection), a permanently installed voltage monitoring device is an alternative to the use of a handheld voltage measurement device.

Providing safe monitoring points for voltage (or remote transmission of measurements) on JBs and other equipment is a way of avoiding contact with energized conductor and may be useful during trouble shooting.

It is recommended that such equipment measures be applied on all phases to cover fault conditions in the installation and to provide some fault-tolerance in the instrumentation itself.

If indicators are used to signal motor rotation, separate indicators for rotation and for no rotation should be provided, so that one indicator is always active. An instrumentation fault exists if either no indicator is or both indicators are active.

**CAUTION**—Direct measurement with hand-held instruments should always be used before working on power cable connections.

### **B.8.4 Drive based**

At a commissioned installation, readout showing motor rotation (speed, voltage or current) from the VSD is a positive indication of unplanned motor rotation.

Readout from the VSD showing no motor rotation cannot be relied upon.

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## **Annex C. (normative) Selection and use of PPE**

The hazard addressed by PPE in this document is the risk of shock or arc flash from and exposure to energized conductors or circuit parts.

**WARNING**—PPE shall be selected based on the risk assessment for the related task. Using inadequate PPE for a given task could result in serious injury or death.

The required electrical PPE will be established by the operator, supplier and national and local regulations based on the voltage and energy level of exposure to the exposed energized conductors or circuit parts for the task being performed.

Arc flash assessment should be divided into consideration of:

- The PMM and ESP power cable, with a minimum of 4 cal/cm<sup>2</sup> for motors up to 350hp (section H.1.1).
- Working with the utility supply and motor drive (using normal assessment procedures).

It may be more convenient to select PPE for the greater level of protection where the electrical worker is involved in all tasks. Figure C.1 shows typical 4 cal/cm<sup>2</sup> [16.7 J/cm<sup>2</sup>] clothing but situations will vary and the rating of the PPE should rise to meet the required protection level.

# **PPE – Hazard Risk Category 1**

## **1.2 – 4 cal/cm<sup>2</sup>**

- 4+ cal long sleeve shirt & long pants (or coveralls)
- Hardhat
- Safety glasses
- Arc rated face shield
- Hearing protection (inserts)
- VR gloves
- Leather gloves
- Leather work boots



Figure C.1—Electrical PPE example.

All PPE and test equipment shall be checked prior to use and in good working order with valid certification where required. Personnel who inspect and use electrical PPE shall be trained on how to correctly inspect and verify that it is safe for use.

**NOTE** Arc flash rated (AR) clothing is also fire resistant (FR). FR clothing is not AR rated unless it is tested for this purpose and a rating assigned.

All personnel shall be appropriately trained to perform the task to be performed in accordance with the requirements of Annex A.

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The job safety briefing with all personnel will identify the risk of electric shock and arc flash with a focus on the unique risks associated with tasks related to PMM.

The electrical PPE requirements to perform a cable splice or install an electrical penetrator system, which involve manual manipulation of conductors, may differ from the electrical PPE required when troubleshooting or commissioning the same system where no conductor access is required. Therefore, specialized training on PMM systems is essential for those involved.

EXAMPLE— The maximum potential rotational speed of the pump and motor shall be considered when establishing the maximum potential generated voltage. EMF will most probably exceed motor nameplate voltage rating if motor rotation speed exceeds motor nameplate speed.

A motor with nameplate voltage value of 2000 V at 3600 rpm could deliver approximately 3000 V when rotating at 5400 rpm.

Access barriers and signage shall be installed in, and around certain areas as designated by the operator and supplier as per the job safety plan (see also section 7.8 and Annex E)



## **Annex D. (normative) Grounding and bonding**

### **D.1 General**

This section covers grounding, which has the following protective and bonding purposes that are not specific to PMMs:

- To return fault currents via a low impedance ground connection to the source, sufficient to activate any protective devices. This is normal practice for all electrical equipment installations and is a requirement of the applicable national and/or local regulations.
- Prevention of static discharge between conductive items or equipment in the hazardous (classified) areas.
- To reduce voltage transients caused by lightning strikes.
- Prevention of hazardous potential differences between any electrically conductive items and contact with the equipment by a worker.

PMM installations extend these requirements because:

- Temporary equipment, principally the cable spooler and the installation rig, are present and are in contact with the ESP power cable.
- Field personnel are required to work on the ESP power cable.
- Motors have a high per unit impedance compared to transformers and utility supplies. The bolted fault currents are comparable to the motor rated currents. Consequently, fault currents from the motor acting as a generator during unplanned motor rotation are not limited to a short time interval by protective devices. The fault current may flow throughout a prolonged period of rotation such as backspin and the cable should be correspondingly rated.

Figure D.1 shows the typical surface equipment grounding arrangement.

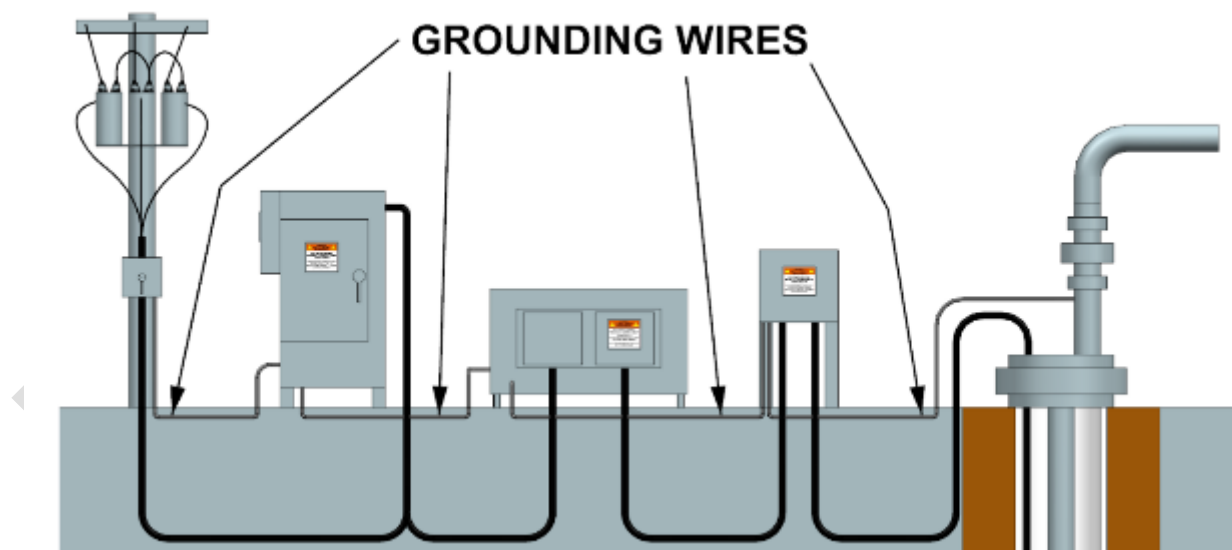


Figure D.1—Conventional grounding of surface electrical equipment.

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## D.2 Recommendations

Figure D.2 shows in physical and schematic form the necessary grounding of a spooler.

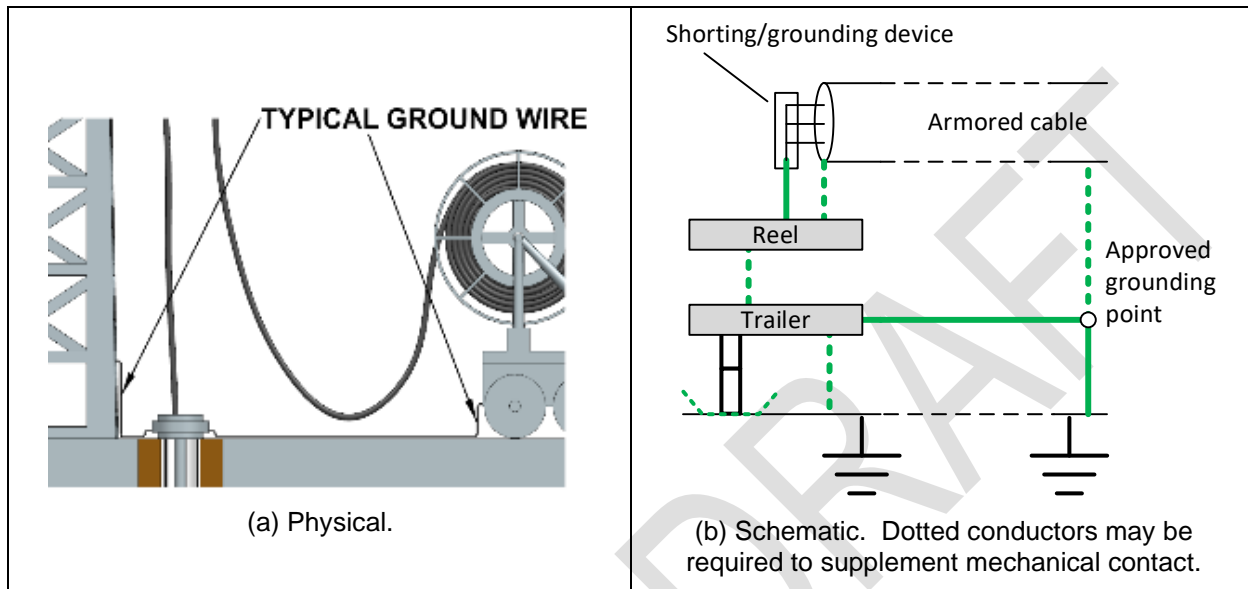


Figure D.2—Equipotential bonding zone at the spooler.

In reference to Figure D.1 and Figure D.2 it is recommended that:

- a) All surface electrical equipment be grounded to the approved grounding point, per normal practice. The surface pigtail and other connection power cables may have an integral ground conductor which can be used in place of a separate ground conductor.
- b) The rig be connected to the approved grounding point.
- c) The cable reel and spooler be connected to a local approved grounding point to establish a grounded equipotential reference for working at the cable end. Grounding of the reel may be achieved by a combination of, and not limited to:
  - 1) Verified low resistance between reel and trailer.
  - 2) Exposed metallic cable armor between reel and well head.
  - 3) A jumper ground cable attached between reel and trailer when work is required.
  - 4) A grounding slipring installed in the spooler.
    - i. In Figure D.2b the dashed lines represent incidental ground connections and may if necessary be improved by additional conductors such as listed above. Note that the equipotential bonding zone includes the local ground at the spooler. The approved grounding point may be at a different potential to this local ground depending on ground currents and the resistance of the ground wire from the spooler trailer.
    - ii. A wooden reel or insulated cable with no armor or with external insulation requires special consideration. As a wooden reel or insulated exterior of the cable would not be conductive, they cannot be grounded. The cable ends can be insulated or can be shorted together, according to the chosen procedure. If the cable ends are shorted together, it is recommended that they are grounded with a jumper wire when access to the conductors is required for measurement. In either case the conductors should be

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tested for absence of voltage before proceeding. If the cable has an externally insulated armor jacket or internal ground conductor, this should be included with the shorted conductors.

- d) At the point of working for a cable splice, the splicing bench (if conducting) and cable armor be locally grounded to an approved grounding point.
- e) Temporary ground conductors should be flexible stranded copper and have a cross-sectional area no smaller than approximately 13 mm<sup>2</sup> or 6 AWG or as national and local regulations require. The ampacity of the selected ground wire size should be reviewed when the ESP power cable is approximately 35 mm<sup>2</sup> or 1 AWG or larger. (These sizes are based on readily available wire sizes used in industry.) An important consideration for this review is that PMM fault currents are typically comparable to motor current nameplate ratings, unlike utility system fault currents.

NOTE The minimum requirement is based on mechanical integrity for field use. Smaller 8 AWG [8.4 mm<sup>2</sup>] can be considered in protected environments and short distances.

- f) The additional grounding requirements be reviewed during job planning and in consultation with the operator's qualified electrician.

Implementation of the local ground may be determined by the nature of the installation and environment (dry sand, damp soil, hard rock, workboat). Examples include:

- Driving a copper ground rod into the soil.
- Relying on the spooler's deployed supporting feet.
- Using a conducting grid in contact with the soil and which the field person can stand on when working on the cable end.
- Where distance permits, additionally using a ground conductor connected to the approved grounding point.
- Connection to a workboat's metal hull, which is in contact with water.

## **Annex E. (normative) Signage and identification**

### **E.1 Locations**

Having clear and prominent signage is an important method for notifying onsite personnel that a PMM is present in each well and what electrical hazards may be present. Typical minimum locations to apply this signage are the VSD cabinet doors, step-up transformer terminal chamber doors, and vented JB. In addition, additional signage may be placed near the wellhead such as on or near the wellhead electrical cable feedthrough, the

Signage should also be used for equipment brought on to location for temporary work, such as RIH, POOH, and maintenance.

EXAMPLES Cable reel, access barriers.

Figure E.1 shows examples of where signage may be placed on the main electrical equipment. Signage should be distinct and distinguishable from other electrical hazard signage to inform people that a PMM with generative ability is installed in the well. Signage should be large where possible. Because the spooler reel rotates, labels are located on all spokes so at least one is always prominent and readable.

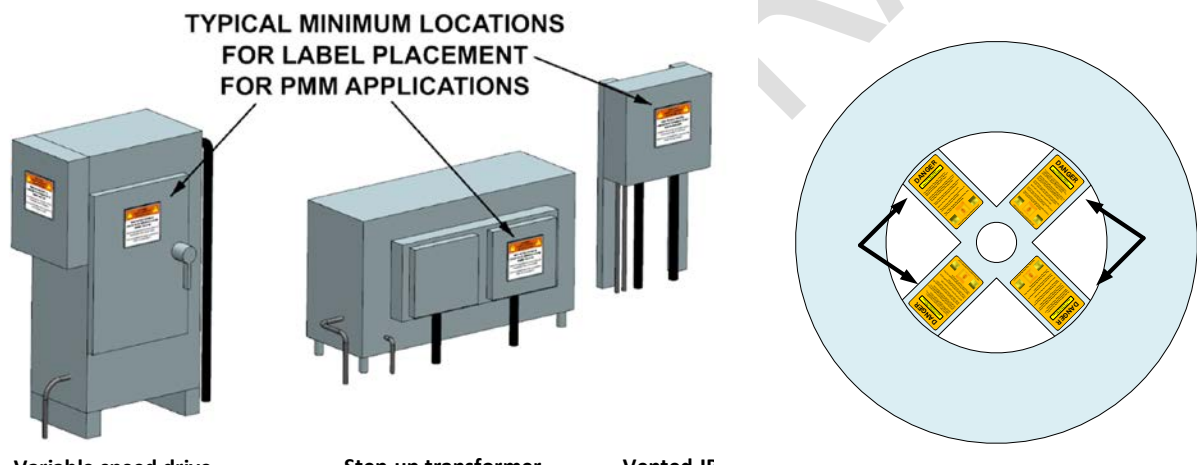


Figure E.1—Example signage locations for permanent and temporary equipment.

Further locations for signage including the wellhead penetrator and staked signage are shown in Figure E.2 below.

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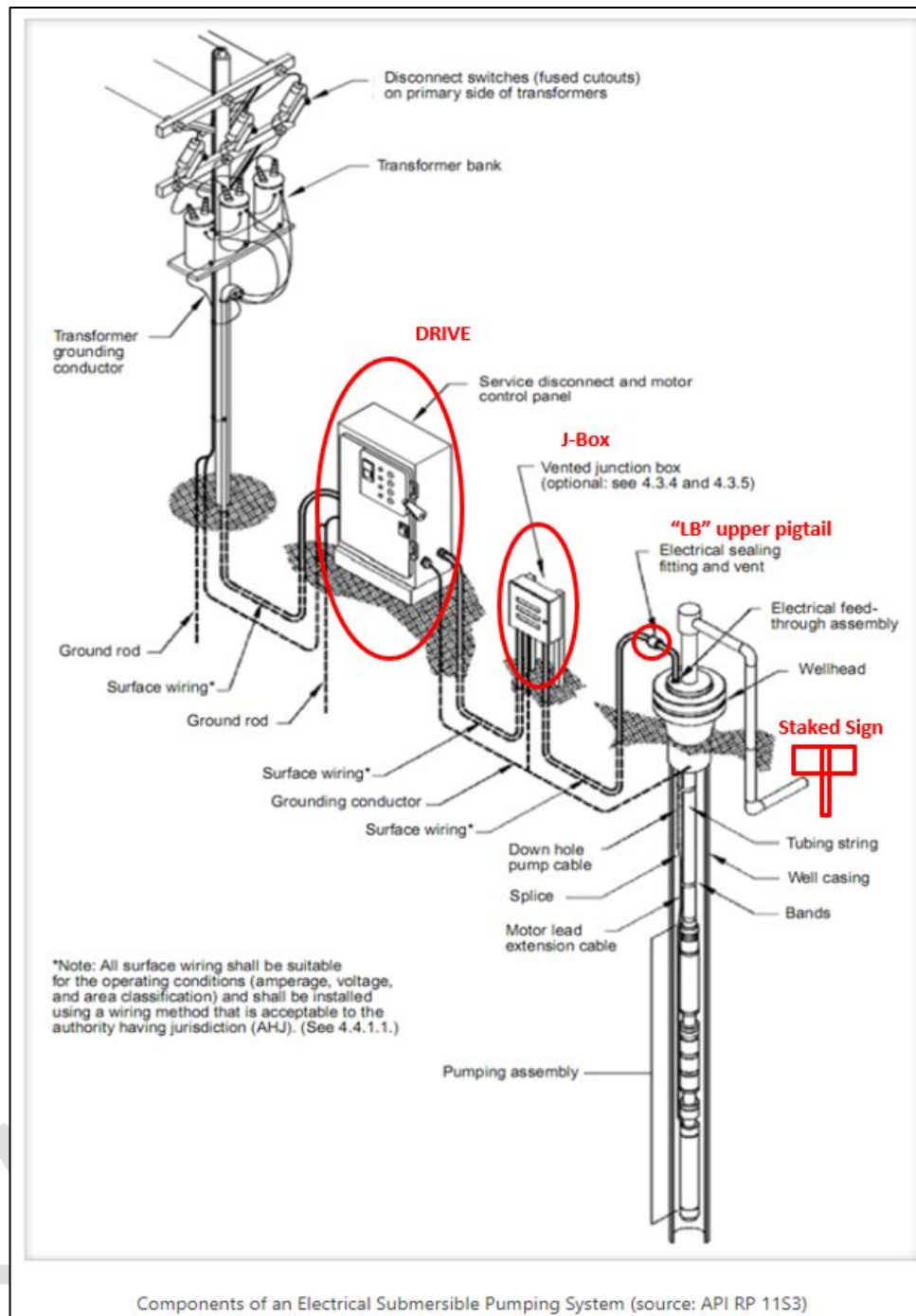


Figure E.2—Other locations for signage.

## E.2 Application

The following are recommendations for the application of signage:

- Consider signage requirements in the job safety planning stage (section 5).

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- Signage should include concise details of the electrical hazards that may be present.
- Signs should be primarily located on non-removable components unless the removable location would impair the use of the equipment if removed.
- Sign size, color(s), font, font size, language, and all other design details should follow the appropriate standards for the local regulatory agencies as well as the operator's and/or equipment supplier's standards.
- PMM and IM well components (such as the penetrator) may be painted different colors to identify PMM or IM usage in the well. If this method is used, both colors should be different than the original color of the device to be painted.

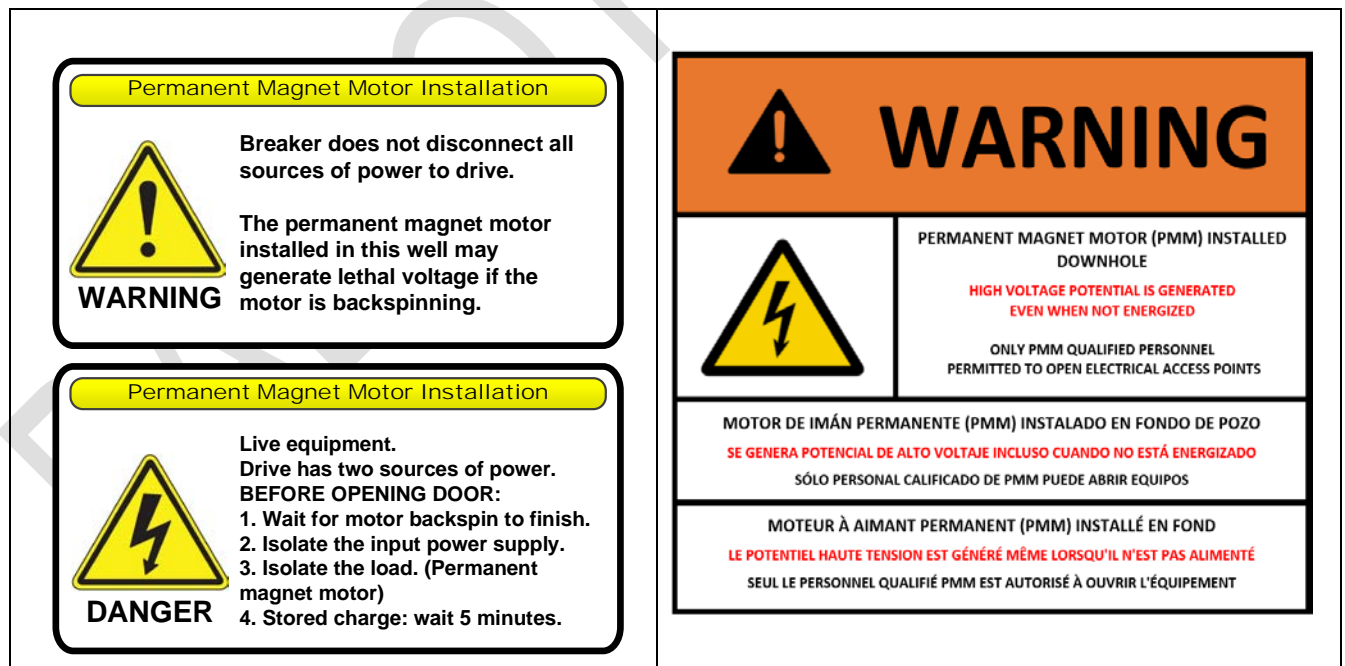
### E.3 Maintenance

It is common for IM systems to be pulled and replaced with PMM systems and vice versa. This can result in misleading signage. Due to this it is strongly recommended that:

- When equipment is moved or changed, the labels should be updated accordingly.
- Personnel always assume a PMM is installed until proven otherwise. The presence or absence of PMM signage does not guarantee the presence or absence of a PMM. The presence or lack of signage does not replace the need for proper electrical checks and LOTO / isolation.

If distinctive coloring is used on a re-usable device, it will require repainting if the PMM or IM system is changed to the other type. Figure E.3 shows examples of labels for use with PMM type applications. Multilingual labels are recommended at locations where English is not the primary language.

Signage about PMM is generally larger than standard electrical hazard, warning, and danger signs.





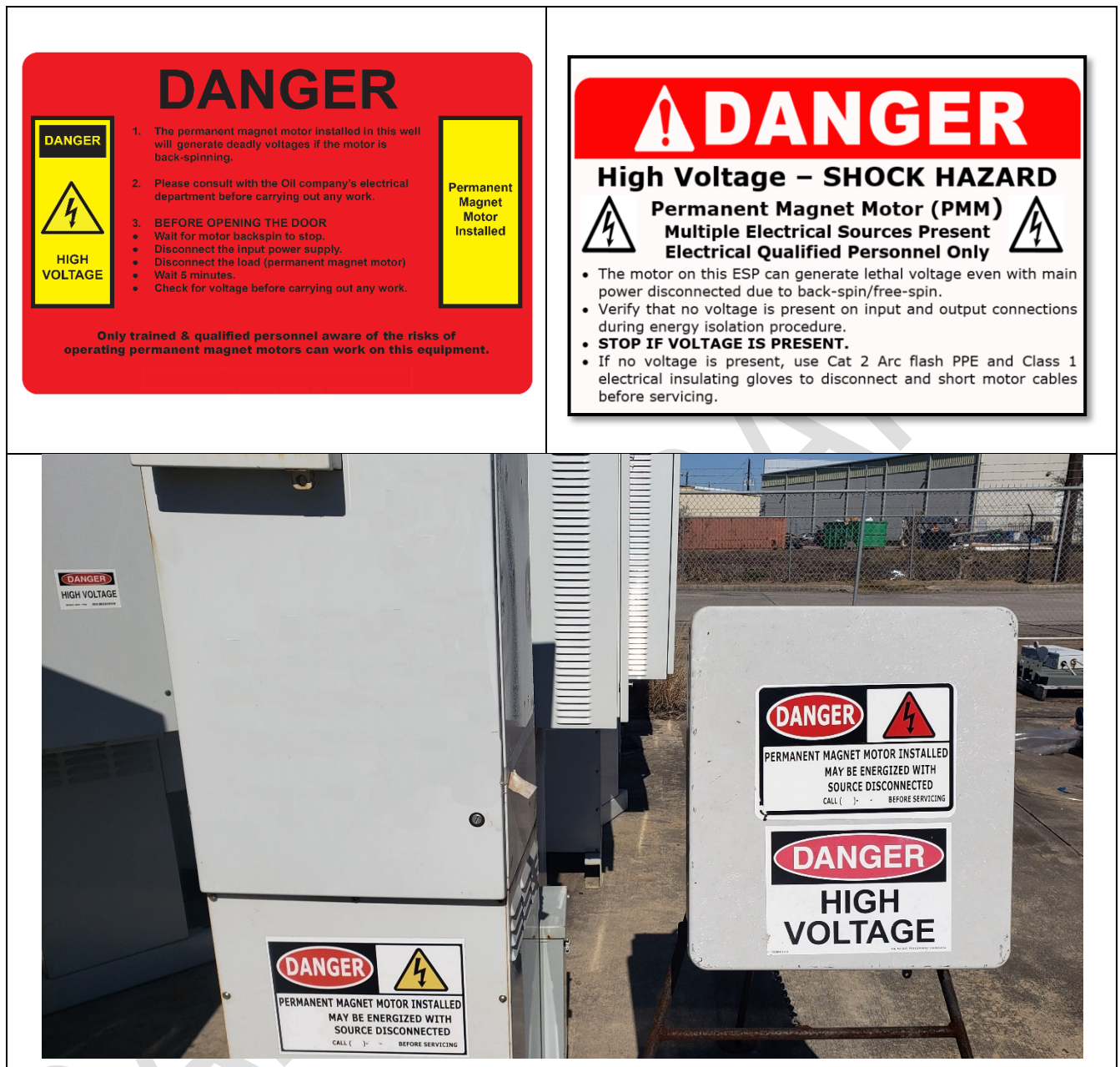


Figure E.3—Example of labels that may be used for PMM applications.

## **Annex F. (informative) Types of PMM deployment**

### **F.1 General**

In this Annex, the types of deployment known at the time of the issue of this document are described below. As PMM systems are very diverse, there is opportunity for new developments and new deployment methods. These may be added as required to future versions of this document.

All deployments result in a BHA set in the well. In general, the BHA may contain many components, including, typically from the bottom of the BHA:

- downhole instrumentation
- motor
- motor seal to protect the motor from well fluid and to compensate for motor oil volumetric expansion and contraction.
- pump intake
- gas separator
- gas handler
- pump
- pump discharge
- discharge pressure section

In some deployments the motor is placed above the pump.

The hazards in this document stem from unplanned motor rotation. This is caused when fluid flowing through the pump in either direction causes the pump to act as a hydraulic motor, which in turn rotates the motor as a generator.

Consequently, the BHA components of most relevance in this document are the pump and motor when they are coupled together. Other BHA components are sometimes mentioned but are not essential to this document.

NOTE Surface pumping systems (section F.8) have the motor at surface and the pump downhole.

### **F.2 Conventional ESP Deployed**

The BHA and attached ESP power cable are deployed on the end of the production tubing (see Figure F.1) for a conventional ESP system. This tubing comprises multiple sections of pipe known as joints, which are added repeatedly until the required pump setting depth is achieved. As each tubing joint is added, the ESP power cable is strapped to its exterior.

The tubing is then connected to and supported by the wellhead. The ESP power cable is connected to a wellhead feedthrough system (see 14.8) and further connected to the surface electrical equipment. The well bore fluid enters the ESP system through the intake or gas separator, flows through the pump and is discharged into the tubing up to the surface.

The pump and motor are always connected with the pump above the motor during both RIH and POOH.



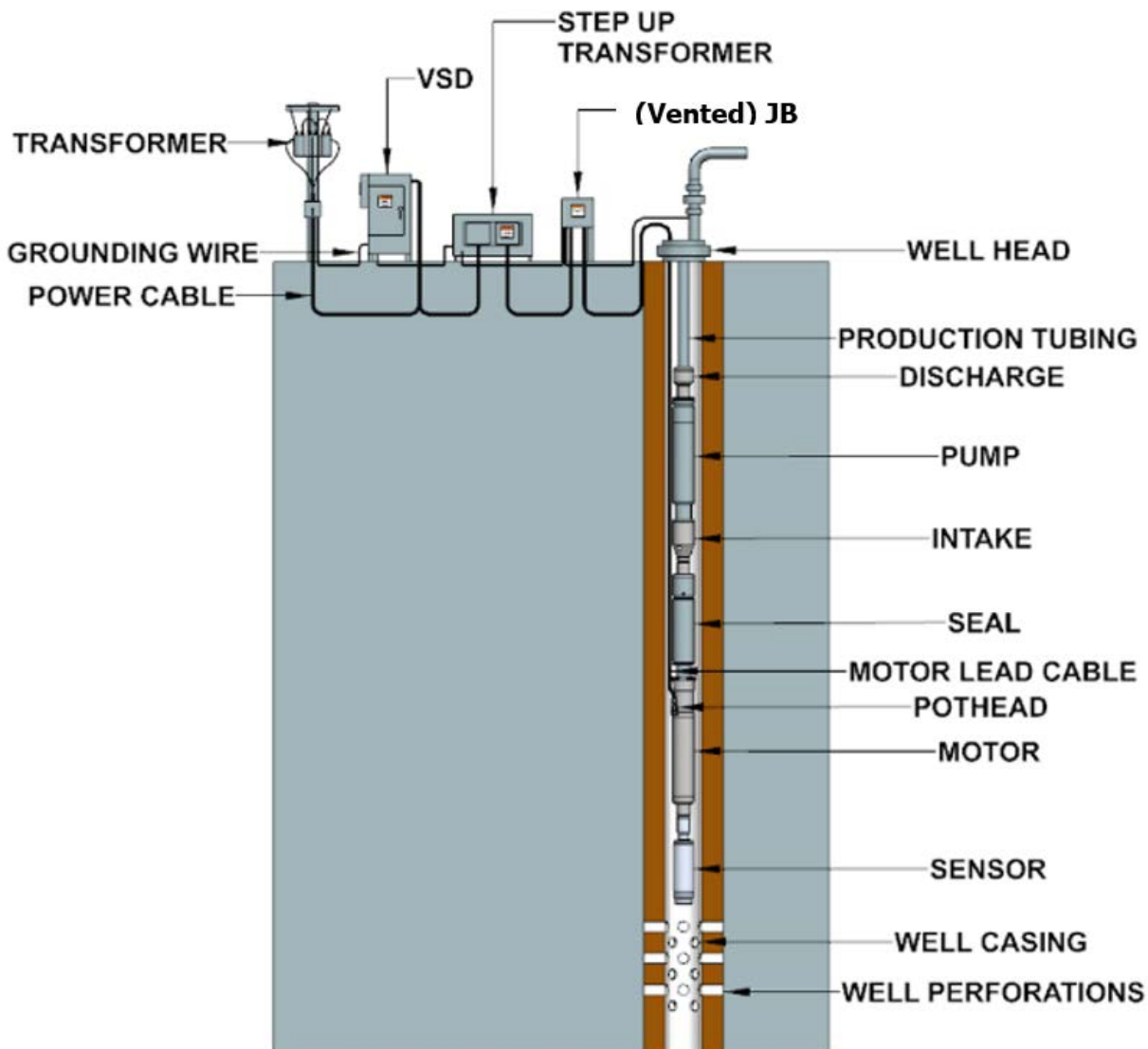


Figure F.1—Representative conventional ESP deployment.

### F.3 Cable deployed

This through tubing ESP system is deployed on a weight-carrying ESP power cable assembly from a wireline winch unit. The pump and motor are usually connected with the motor positioned above the pump in an inverted position.

Figure F.2 shows the deployed BHA. The pre-installed production tubing is terminated at the setting depth with a BHA seating mechanism. In this case the seating mechanism comprises a latch and packer. The BHA is then run into the tubing. Deployment is complete when the BHA is latched and sealed to the tubing with the packer. The surface electrical equipment is then connected to the ESP power cable.

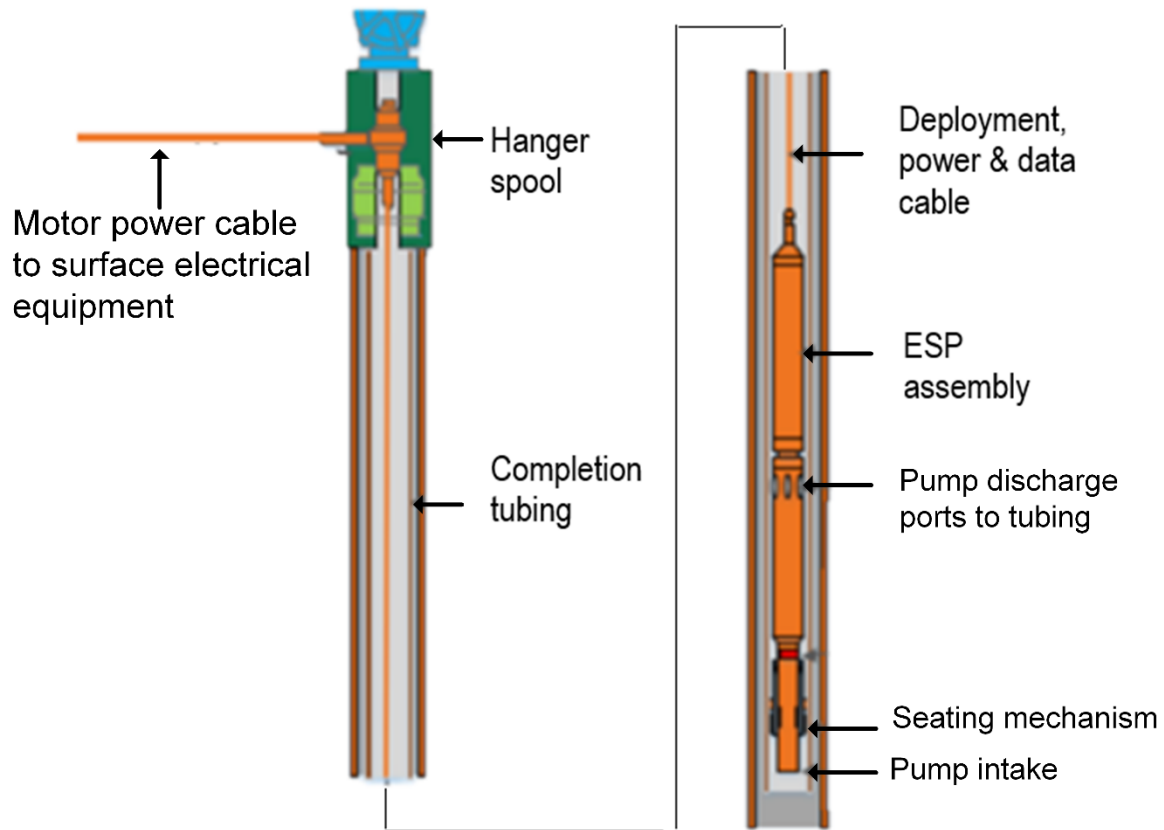


Figure F.2—Cable unit deployed ESP after completion.

Fluid is pumped from the casing up through the tubing like a conventional ESP system.

The ESP power cable assembly comprises a weight-carrying element and the ESP power cable. Implementations include:

- Tubing encapsulated cable. The ESP power cable is contained within small diameter continuous tubing.
- ESP power cable with stranded armor.
- ESP power cable strapped to a support cable.

The motor and pump are inverted compared to conventional deployment. This allows the ESP power cable to be attached directly to the motor without having to pass down over the pump body.

Other configurations and applications of this through tubing reeled cable deployment are possible. Each of these well applications and configurations have their specific considerations.

**EXAMPLE** – For short term well intervention, the ESP power cable assembly remains connected to the wireline unit via the pressure control equipment and the downhole equipment may or may not be latched and sealed into its seating mechanism.

Unplanned motor rotation can occur similarly to conventional ESPs: when the BHA is being tripped in or out of the well (see section 5.4.8), when latched and during back spin and well kicks.

#### **F.4 Through Tubing: Threaded or Coupled Tubing**

ESP systems which are installed through the tubing wherein the ESP power cable is installed either concentric or exterior to the deployment tubing which carries the weight of the ESP system.

The system components are identical to the conventionally deployed ESP system. Cable, sensor, motor, seal, and a lower mating unit are RIH and retrieved with the threaded or coupled tubing. An upper mating unit, intake and/or gas separator and pump(s) are RIH and retrieved with wireline.

Once the pump is landed, then two additional wire line runs are required to land the pump discharge pack off and anchor, which locks down the pump. Until the pump discharge pack off is set, the intake and pump discharge are in direct communication.

The risk of electric shock or arc flash from unexpected motor rotation exists while RIH or POOH when the pump is run coupled to the motor. The risk is diminished when the PMM is installed/retrieved separately from the pump.

#### **F.5 Through tubing: coil tubing deployed, external cable**

An ESP system wherein the cable is exterior to the coil tubing (CT) and is both installed and retrieved with the ESP. Deployment utilizes a CT unit and cable is banded to the CT. Typically, the deployment of this type of ESP is done with the pump is coupled to the motor as an assembly.

The risk of electric shock or arc flash from unplanned motor rotation exists while performing both RIH and POOH when the pump is run coupled to the motor. The risk is significantly diminished when the PMM is installed or retrieved separately from the pump.

#### **F.6 Through tubing: coil tubing deployed, internal cable**

An ESP system wherein the cable is installed interior (concentric) with the coil tubing (CT) and is retrieved with the ESP. See Figure F.3 for a typical configuration of this system. Deployment utilizes a CT unit and integrated CT and Cable assembly. The ESP is run in an inverted orientation with the pump at the bottom and motor at the top. Typically, the deployment of this type of ESP is done while the pump is coupled to the motor as an assembly.

The risk of electric shock or arc flash from unexpected motor rotation exists while running in the hole when the pump is run coupled to the motor.

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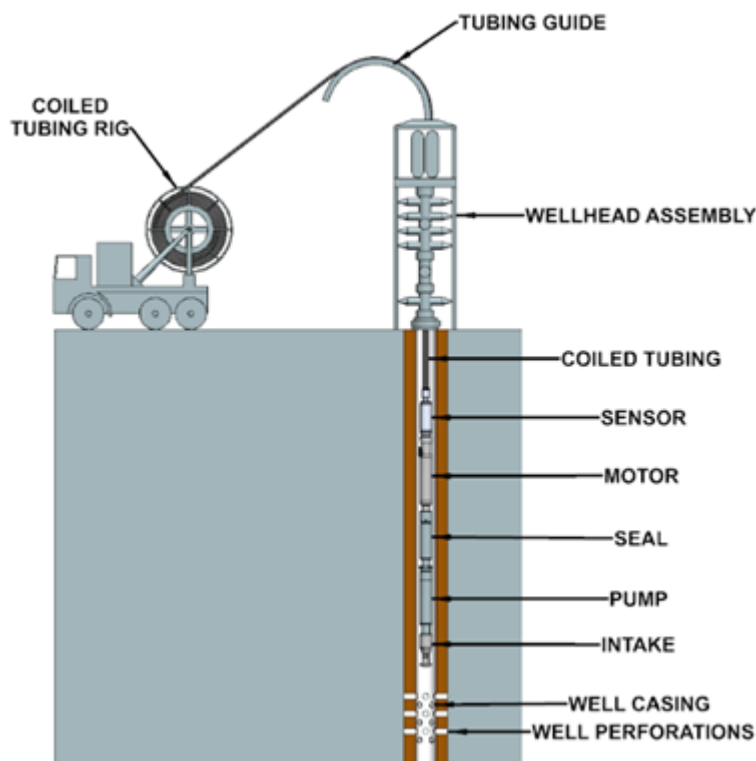


Figure F.3—Coiled-tubing deployment, internal cable.

## **F.7 Docking station deployed**

### **F.7.1 Single stage deployment**

This through tubing ESP system uses cable, wet mate electrical connector and associated completion kit deployed on threaded and coupled tubing. The ESP system is deployed with a single run in the hole after the tubing and wet mate connector (docking station) are landed and the wellhead is nipped up. The ESP is retrieved and replaced without pulling the tubing and cable using braided line or electric line. Coiled tubing, rods, jointed pipe, and/or other retrieval/deployment means may be used for this and the modular systems but are not as commonly implemented and do not change the safety considerations.

Typical installation will assume landing the retrievable ESP string inside the docking station once the docking station is 200 ft below the wellhead and continuing to run the tubing with external cable to ESP setting depth. In this respect, from the moment the ESP is landed inside the docking station, there is risk of hazardous voltage or shock from unexpected motor rotation while running in the hole since the pump is run coupled to the motor.

**NOTE** The single stage system may utilize an IM or a PMM. The risk only exists with the PMM (see also section 4).

**CAUTION**—Because the PMM looks the same as an IM outwardly, the motor type shall be verified.

### **F.7.2 Modular stage deployment**

This through tubing ESP system uses cable, wet mate electrical connector and associated completion kit deployed on threaded and coupled tubing. The ESP system is typically deployed with multiple wireline or slickline runs after the tubing and wet mate connector (docking station) are landed and the wellhead is assembled. The ESP is retrieved and replaced using wireline or slickline without pulling the tubing and cable. Typical initial installation will include landing the motor inside the docking station when the docking

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station is 200 ft below the wellhead and continuing to run the tubing with external cable to the ESP set depth. Only when the pump is installed and coupled to the motor is there is risk of EMF from a rotating PMM.

Some installations may be performed with the complete ESP system installed before RIH is completed and the tubing hanger landed. The risk of hazardous voltage or shock from unexpected motor rotation exists while running in the hole when the pump is run coupled to the motor.

Never assume that the ESP system is landed only after the tubing is landed. Once the pump is mated to the motor the potential of shock from EMF will be present. The decision of when to load the complete ESP system is decided by the operator and supplier. Due to the limited flow path between the pump and tubing the potential of EMF exists even before the pack-off which isolates the pump intake from the pump discharge is installed.

## **F.8 Surface PMM**

PMMs are now in use at the surface with artificial lift systems and facilities. In most instances these surface PMMs look like conventional induction motors in both physical size and shape

Surface applications are typically progressing cavity pump (PCP), reciprocating (sucker) rod pump (SRP or RRP), horizontal pumps and facility transfer pumps. PMMs may also be used to drive power fluid at the surface as seen in hydraulic lift (Jet and Piston) pump systems.

### **F.8.1 PCP systems**

The drivetrain transmission consists of a motor, belts, sheaves, and a surface drive unit sitting on top of the wellhead. This configuration is commonly called a top-drive PCP. The PMM can be substituted for the induction motor in the top-drive arrangement, or it can be utilized in a direct-drive application to replace the drive transmission (belts, sheaves, etc.). As a direct drive, it offers increased system efficiency. Risk of electrical shock exists from unexpected motor shaft rotation when not under utility generated power. The risk can occur during rod backspin, well kick or fluid fall in the tubing. Installation risk is not present while the pump and rods are run in hole (RIH) because the motor is not mechanically linked to the pump string.

### **F.8.2 Reciprocating (sucker) rod pump systems (SRP or RRP)**

Surface units come in numerous forms but fall into three main categories: beam, air balanced and hydraulic. SRP utilize a prime mover (gas engine or electrical motor) to convert rotational mechanical linkage into reciprocal action for the downhole pump. With PMM and beam units, the motor is directly mounted to the gearbox shaft to drive the pumping unit to eliminate the need for belts and sheaves to increase system efficiency. The PMM in this manner is considered a direct drive motor.

SRP systems are positive displacement pumps with two or more valves (traveling / standing). While a well kick or fluid loss in the tubing would require a tremendously large force to translate vertical motion into rotational motion via the horsehead linkage to generate a PMM voltage, caution should be used during any type of intervention with any PMM system due to the generative mode of such motors. Personnel should never enter the hazardous area of crank arms unless the SRP unit is braked, and crank arms secured. Any intervention with the surface electrical equipment requires full consideration of the power isolation, LOTO recommendation and proper procedures. Then and only then can the motor be installed or replaced or repaired. That said, risk of electrical shock exists from the PMM if the shaft rotates. The level of voltage is not at the high levels as with ESP or PCP, but it is still hazardous.

## **Annex G. (informative) Progressing cavity pumps**

### **G.1 Progressing cavity pumps**

Progressing cavity pumps (PCPs) are widely used in heavy oil, gassy, and sandy wells due to their low-speed, positive displacement, and robust design.

PCPs are presently the only positive displacement rotational pump system which can be operated by a motor either at the surface or downhole.

A shear out valve (SOV) allows an over-pressure event to open the valve and relieve pressure. As a PCP is a positive displacement pump, it is important to consider the possibility of bursting the tubing when the well is shut in. This could occur during inadvertent (or planned, such as mechanical integrity test (MIT)) shut in of the wellhead while the pump is in operation, causing unplanned fluid flow somewhere in the tubing string. The use of a check valve or a pump that has high breakout torque will leave a tubing nearly full of fluid and pressure in a shut-in well will build up rapidly upon starting.

The great majority of PCP installations are rod-driven from surface (section F.8.1). In these systems there is no ESP power cable, so the electrical hazards associated with unplanned motor rotation during RIH and POOH are absent.

An increasing number of wells now use downhole-driven PCPs. Typical applications include heavy oil, deviated wells and wells with high doglegs above the setting depth, where friction and wear in rod-drive systems can lead to poor efficiency and reliability.

Downhole driven PCPs take several forms as shown in Table G.1.

Table G.1—Downhole-driven PCP methods.

Surface	Downhole
No step-up transformer	Direct drive from low pole-count motor
Step-up transformer	Direct drive from high pole-count motor
Step-up transformer	Gear-motor drive, low pole-count

The gear-motor driven systems operate the motor at conventional speeds whereas the direct-drive systems operate the motor at the pump speed.

#### **G.1.1 Pump characteristics**

The primary pumping characteristics of an ideal PCP are that flow rate is proportional to speed and motor torque is proportional to pressure (head) across the pump, but independent of speed.

In real PCPs, the flow rate at a given speed reduces as pressure across the pump increases. The reduced flow is a consequence of leakage between stator and rotor. Typically, the pump rated head is specified at 300 rpm and where 25% of the ideal flow is lost through leakage.

A PCP comprises a rotor and a stator. The stator may be metallic or elastomeric. Elastomeric stators typically have a high breakout friction, which is the momentary torque required for the pump to start turning. Once the pump starts turning, there is a lower running friction torque in addition to the torque needed for fluid lift.

The actual friction may differ from the pump datasheet, as the rotor-stator fit is adjusted during manufacture for the expected well conditions and effect of fluid on the elastomer. The fit may change

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after installation due to elastomer swelling. Metallic rotors are made with a relatively loose fit and have low friction. Uncertainty in friction can make unplanned motor rotation uncertain as well.

These characteristics introduce new factors to the risk analysis and safety measures compared to hydrodynamic pumps, which are relatively free flowing when stationary.

When the motor is not connected or driven, and pressure across the pump, in either direction, is sufficient to overcome breakout torque, the pump will start to turn. It will accelerate very quickly to a high, potentially damaging, speed, and will continue to rotate so long as the pressure exceeds the running friction. It will then stop, leaving a residual fluid head. Depending on the rotor-stator fit, fluid may continue to leak until the fluid almost equalizes. In direct-drive systems it is possible the drive will be damaged from over-voltage unless it has voltage-limiting equipment.

In the absence of any prevention of rotation measures:

- In normal operation, a stop for any reason, such as loss of supply power, trip, or commanded stop, may initiate back spin. If backspin does not start, the fluid column in the tubing will maintain pressure on the pump. There is the risk that backspin will occur at some future time.
- During RIH, reverse pressure will build up across the pump as the non-rotating pump is a form of plug and the tubing will be empty apart from leakage. When the reverse pressure exceeds breakout, the pump will forward spin. A well kick will have the same effect.
- During POOH, the tubing fluid will be carried up with the pump, so developing a positive pressure relative to the casing fluid. When this exceeds breakout, the pump will backward spin.

### **G.1.2 Damage**

Due to the potential for PCP and drive damage from high speed in all phases of well operations, PCP installations require instant-acting methods to limit or prevent rotation when the drive is stopped or loses control of the motor. These methods may also serve to mitigate safety risks:

- Surface drive rod systems (section F.8) typically employ mechanical braking equipment, which addresses both the unwinding of the rod and stopping of the pump in normal use. During RIH and POOH the rotor is not installed in the stator.
- Suppliers of downhole driven systems may provide speed-limiting apparatus downhole or at surface or require a check or diverter valve in the tubing above the pump (section 5.4). Gear-motors may resist pump rotation.

### **G.1.3 Safety**

Unlike hydrodynamic pumps, running tubing during RIH or POOH does not cause rotation because of trip speed. Rotation will commence and accelerate rapidly when/if sufficient pressure is developed across the pump to overcome breakout torque.

Section 5.4 provides recommendations for prevention of unplanned motor rotation. In some circumstances, filling the tubing to maintain approximately equalized pressure across the pump may be an option, ideally in conjunction with downhole gauge pressure measurements.

**NOTE** Sliding sleeve valves and retrievable plugs require manual interventions and cannot provide instant protection against damage during normal operations. The completion should employ equipment that both provides safety and eliminates damage during all phases of operation.

## **Annex H. (informative) Arc flash pertaining to PMMs**

### **H.1 Background**

With sufficiently high available electrical energy, an arc flash event is characterized as an electrical explosion often resulting in major equipment damage. When a person is near the arc flash, serious injury or death can occur. At lower electrical energy that may be typical of downhole PMMs, the event may be limited to thermal burns.

Shock and arc flash assessment is done to establish approach boundaries and determine PPE within that boundary to protect personnel from electric shock or arc flash.

**NOTE** This assessment is not intended to be performed for work in a hazardous area where there is potential for a chemical (fuel, air) explosion. For this condition, having an electric arc trigger an explosive atmosphere has much more damage potential and a larger “boundary” to consider.

Arc flash can be caused by many things including:

- Contamination of the surface of exposed energized electrical conductors or circuit parts by conductive dusts, condensation or other substances resulting in the creation of a conductive path to ground or another energized phase.
- Dropping of tools or use of tools
- Incidental touching of energized conductors or circuit parts.
- Insulating material failure
- Faulty Installation, e.g., loose cable terminations, handling of energized PMM cables with insulation damage.

Three factors determine the severity of an arc flash injury:

- Proximity of the worker to the hazard
- Arc temperature arising from fault current.
- Time for fault to clear or for personnel to egress from fault area.

Because of the nature of an arc flash exposure when an employee is injured, the injury is serious – even resulting in death. Results from an arc flash, which vary in intensity, include:

- Burns
- Fire
- Flying objects
- Blast pressure
- Sound Blast
- Heat

#### **H.1.1 PMM arc flash**

A PMM subjected to unplanned motor rotation is a source of electrical energy. The electrical energy ultimately comes from fluid flow through the pump, and will vary widely according to fluid head, flow rate, and pump conversion efficiency.



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EXAMPLE – A conventional centrifugal pump, when driven into rotation by fluid, acts as a turbine that drives the motor. As the fluid column equalizes, the turbine speed and power declines falling to zero when rotation ceases.

Other recommendations in this document serve to eliminate or greatly reduce arc flash risk in most circumstances:

- No SIMOPS.
- Prevention of rotation devices.
- Using shorted and grounded conductors.
- Increasing the distance between technician and the point of working on conductors that are not shorted and grounded, such as use of extended voltage probes, will reduce the incident energy.
- Use of non-hazardous voltage monitoring points for checking voltage and current on the ESP power cable.

No SIMOPS ensures that in most circumstances the risk when working on cable conductors is due to a well kick. The motor will be at zero speed and then shall build up speed to the level at which a flash could occur. Continuous monitoring for rotation may give sufficient warning to cease work before the flash could occur. The energy in an arc will act to slow the motor down.

## **H.2 Fluid injection**

Fluid may deliberately be injected down tubing and through the pump for certain well servicing operations. It may accidentally be injected by incorrect valves settings on commingled wells. In these circumstances the pump could drive the motor to higher speed and power than unplanned motor rotation from backspin or a well kick.

Ordinarily, injection would not be simultaneous with electrical measurements (no SIMOPS).

If measurements are being made for monitoring or trouble shooting purposes, there is a risk of arc flash. This possibility should be considered when making an arc flash assessment.

## **H.3 Incident energy analysis**

There are no known national or international standards that directly cover the circumstances of unplanned motor rotation, specifically because of relatively low fault currents, the (variable) motor electrical frequency and the limited power availability from the fluid source. However, the physical basis of arc flash and a guide to evaluation may be found in the paper by R.H. Lee<sup>[6]</sup>, and helpful explanations in IEEE 1584:2018<sup>[7]</sup>. Use of these documents requires some judgement relating to the application and any analysis can only be an estimate.

Arc currents available from downhole motors, and over long cables, differ from normal utility arc flash calculations:

- Motor and cable per unit impedance is more than an order of magnitude higher than typical transfer impedances, resulting in much lower arc currents.
- Unlike utility equipment, fast-acting circuit breakers and fuses are not used on the motor load circuit as the short-circuit currents are comparable to operating currents and would not trip the devices. It is recommended to consider a two-second egress time.
- The source of the arc flash energy is the fluid that drives the pump. It is unlikely that there would be sufficient fluid power to sustain high power arcs typical of comparably rated utilities.
- Unlike a fixed-frequency utility, the pump speed will vary and will reduce as the fluid column equalizes across it. Available power reduces as the speed reduces.

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Use of the above IEEE standard will typically produce a range of incident energies at 18 – 24 in distance varying from less than 1 cal/cm<sup>2</sup> to 4 cal/cm<sup>2</sup> as 1000 hp is approached. In selecting arc flash PPE rating, a substantial margin should be applied.

#### **H.4 Arc flash risk assessment**

It is recommended that for motors up to 350 hp a minimum of 4 cal/cm<sup>2</sup> arc-flash rated PPE be specified for working within the access barrier. This assessment is based on the independent experience of incident energy calculations made by several of the committee members with a working distance of at least 18 inches.

NOTE 4 cal/cm<sup>2</sup> rating is typically associated with protection from thermal burns. High energy explosions and other effects are assessed to not occur.

For higher-power motors it is recommended that incident energy analysis be performed, and conservative arc flash PPE rating be selected. Analysis may require supplier calculations.

See Annex C for further consideration of rating, and recommendations.

## **Annex I. (informative) Open and closed ESP power cable ends**

### **I.1 General**

This annex provides technical information underlying the behavior of PMMs when the cable conductor ends are left open or are shorted together and expands on section 4.3, electrical protection. The motor is undergoing unplanned motor rotation, in other words it is not being driven by the surface electrical equipment.

### **I.2 Phases open**

When the phase ends are not connected to each other, there will be both phase to phase and phase to ground voltage proportional to the speed at which the motor is being rotated. If the motor is rotating at rated speed, the phase-to-phase voltage will typically be near the nameplate voltage rating. However, no current will be present as there is no path for the current to flow. If this method is utilized for a given operation, it is necessary that the technician utilize appropriate electrical safe work practices to prevent incidental contact with potentially energized conductors or circuit parts.

Figure I.1 illustrates how the voltage generated by the motor is proportional to the speed at which it rotates. The motor in the example is rated for 1545 V at 3600 rpm. When the motor shaft is forced to rotate at 3600 rpm with no electrical power source provided to the motor, the motor generates just under 1400 V EMF. For most motors, the voltage created will be near the nameplate value when rotated at rated speed.

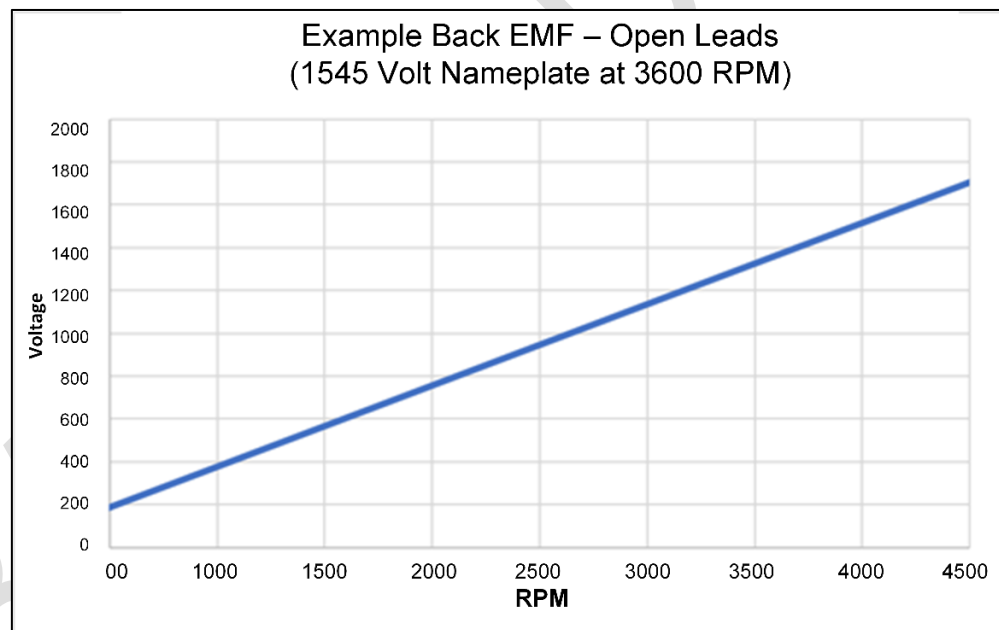


Figure I.1—PMM EMF voltage measured when shaft rotating.

Figure I.2 is an example of the voltage measured during backspin of an installed PMM in a conventional configuration (a different motor than the example above). The rotation is caused by the backspin of the pump due to the fluid in the production tubing falling back after the motor is turned off. In this example, 3700 ft of fluid was above the ESP assembly. This generated approximately 90% of nameplate voltage at shut down and decreased to no voltage over 8 minutes. Speed reduction is linear with time in this

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example. The initial moments of backspin usually are at a higher speed that reduces very quickly, followed by a slow rate of decrease typically over minutes to an hour.

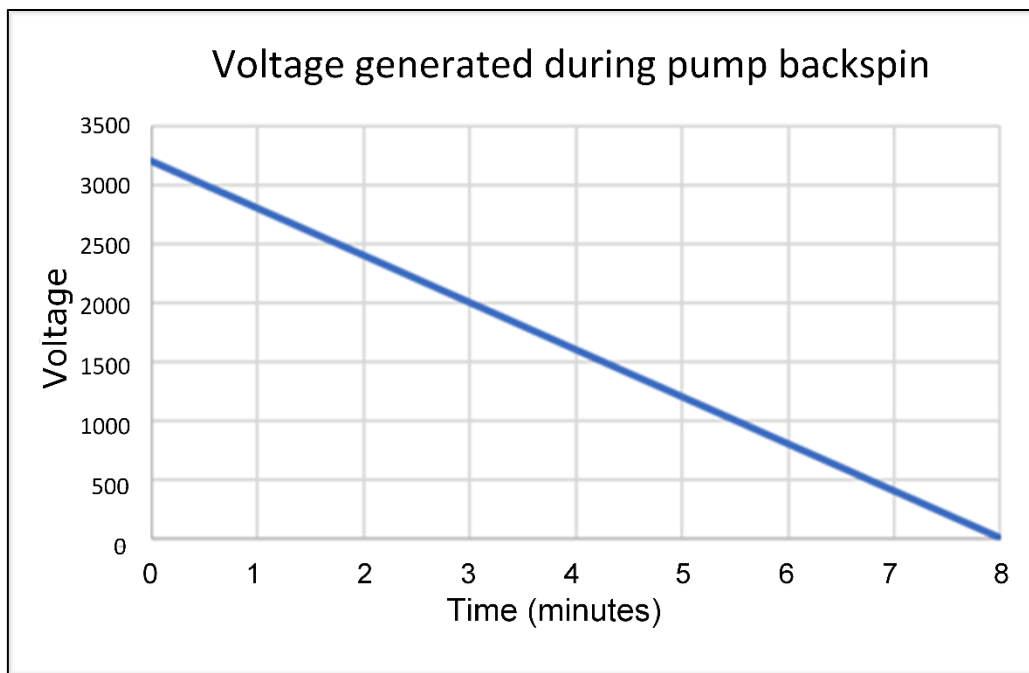


Figure I.2—PMM EMF Voltage generated during backspin.

### I.3 Phases shorted

When the phase ends are connected to each other (whether connected to ground or not), a dynamic brake is created. When the pump (acting as a turbine) drives the motor shaft, the motor's generated EMF drives a current through the motor windings and cable. The shaft power is converted to heat by the current flowing through the conductors. As the pump drives the motor shaft faster, additional braking action is created that resists rotation (there is no braking action without shaft rotation). There can be significant current generated during braking (such as achieving nameplate current of a 3600-rpm motor by only rotating at a few hundred rpm). The current magnitude levels off at high speed. At some rpm (application specific due to considerations such as the electrical system resistance and motor winding), a maximum torque will be generated. When this rpm is exceeded, the braking torque of the motor decreases. The motor will accelerate to the point where the turbine curve crosses the braking curve. Removal of the short (for splicing or other cable preparation) may present additional risk if there is trapped fluid due to acceleration of the pump, and hence motor EMF, as the braking action is removed.

**NOTE** The motor short circuit current will be limited by the speed and torque delivered by the source of motor shaft rotation. A pump driven by back spin or forward spin will typically be unable to drive the motor in short-circuit conditions to reach its maximum theoretical short-circuit current since the braking torque opposes the pump and is considerable.

For some operations, it may be necessary to remove a short and transition to open phases (such as for performing downhole insulation system checks). Prior to removal, the system shall be verified to not be energized and any applicable LOTO performed.

**WARNING**—If the electrical system is energized, several issues could occur: a sudden increase in motor speed, generation of sparks and exposure of personnel to hazardous voltage.

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In conductor preparation, sufficient space for placing an ammeter clamp or related current detector device should be prepared prior to implementing the initial short. Applicable PPE such as hot gloves will also be required during any transition to or from open and closed leads.

If the pump is a PCP, its torque curve is essentially independent of speed and so the torque shall be less than the peak braking torque, if the braking is to be able to limit the speed.

Figure I.3 shows the braking action of a PMM whose cable end is shorted on all three phases. The current and braking power rise rapidly at low speed, then level off. The torque rises very rapidly with speed, then it peaks and reduces thereafter. Although there is no voltage at the shorted cable ends, the EMF within the motor increases continually in proportion to the speed. Figure I.5c and its accompanying description shows how the phase to phase and phase to ground voltages develop from zero at the shorted and grounded cable ends, then increase slowly along the cable before rising quickly with the motor itself.

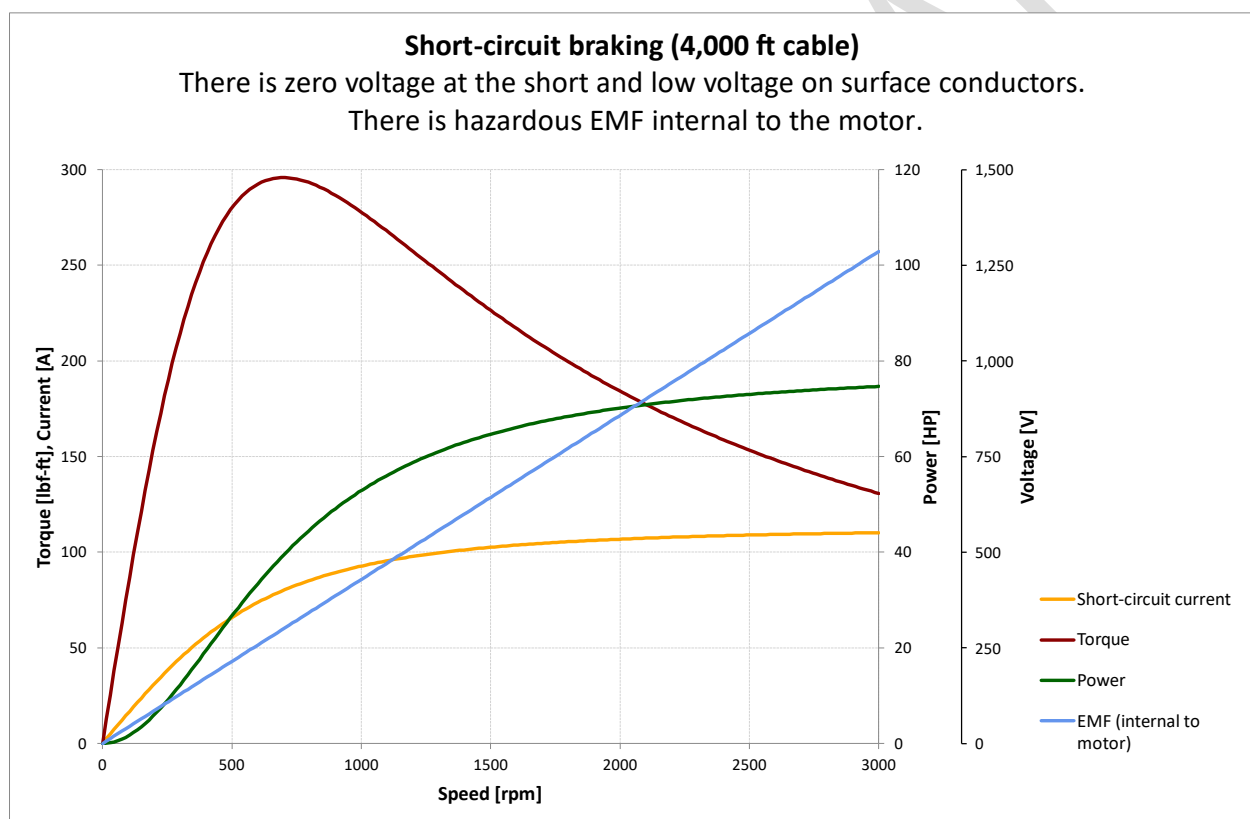


Figure I.3—PMM short-circuit performance curves.

One benefit of this approach is that the generated voltage will be significantly less than when the phases are left open, as the motor speed is reduced by braking. The phase-to-phase voltage on the cable will reduce with distance from the motor until it is at or near zero at the short. At a point several thousand cable feet away from the short, the voltage may be several hundred volts. As the wye point in the motor is floating, there may also be phase to ground voltage that is developed even at the shorted connection (such as with a downhole ground fault situation).

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An additional consideration is the impact of an imperfect short or ground as well as insulation damage other than at the shorting location. In these situations, both phase-to-phase and / or phase to ground voltage exposure at the imperfect short / ground or at the insulation damage is possible.

If two phases are shorted at the end of the cable, there will be no voltage at that point between the two phases. However, there will be significant voltage between the two phases and the open phase.

Another consideration is that between the shorted location and the motor terminals, voltage will appear between all phases. This is because of the resistance of the conductors. Depending on the system specifics (such as cable length, motor rotational speed, etc.), the level of voltage may be significant.

For the same 1545-volt motor with two of the cable ends shorted and one left open, the voltage and current vs rpm as measured at the motor terminals is shown in Figure I.4. In this scenario, there is a significant length of cable located between the motor terminals and the shorted end. This is to illustrate the voltage that may be encountered if the shorting is not performed at the point of work. At the motor terminals, the voltages will not necessarily be balanced between the phases. One phase also shows no current (the open phase). Measurements at the shorting location would indicate voltage on the open phase (no current) relative to the shorted phases, and in a floating system, to ground. There will be current on the shorted phases, which results in some braking torque (approximately half that of a three-phase shorted system).

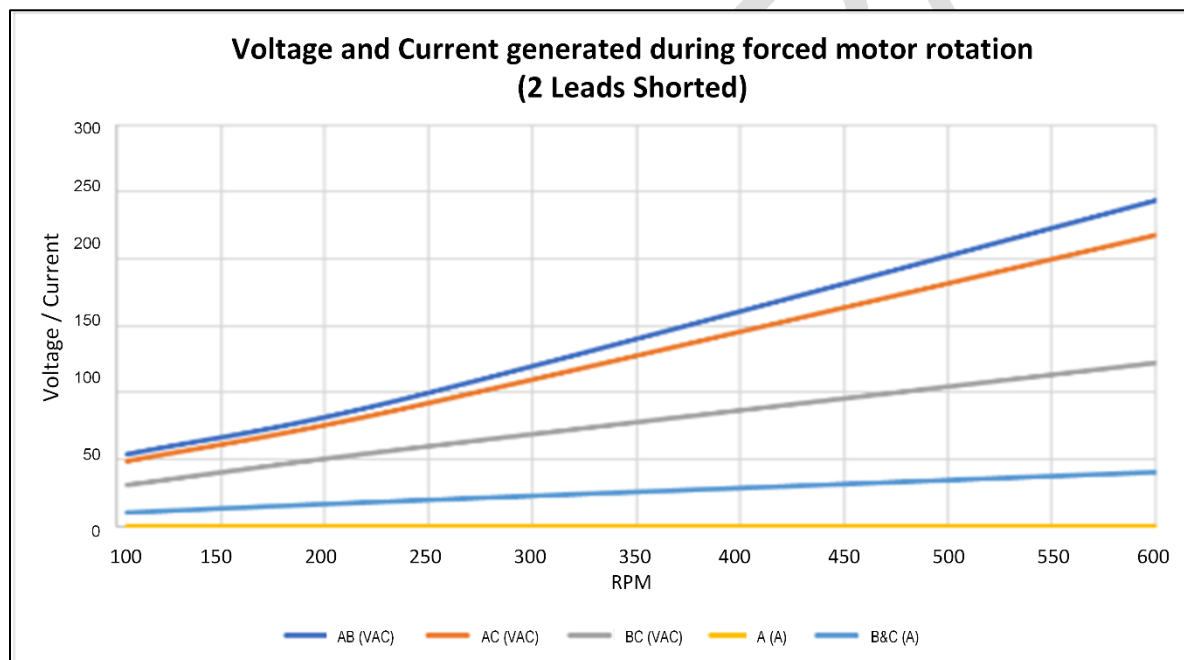


Figure I.4—Voltage and current with two phases shorted.

#### I.4 Comparison of voltages with shorted or open leads

The figures in this section provide a comparison for the voltage that may be seen on the cable ends for several primary methods of preparing the cable ends along with some common issues that may be encountered. The voltage profile along the length of the cable from the motor to the point of working is also shown.

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#### **I.4.1 Undamaged installation**

Figure I.5 shows voltages along the cable from motor to surface in an undamaged installation for three different methods of addressing the conductor contact points. For each scenario, the motor is assumed to be turning at the same speed.

Figure I.5a: The surface phase connections are open, so there is no current flowing in the conductors. The cable voltages are the same throughout its length, equal to the EMF (phase-phase) and  $\frac{EMF}{\sqrt{3}}$  (phase-ground) in a balanced system. Touching the exposed cable conductor ends or a damaged part of the cable is dangerous.

Figure I.5b: A recommended practice in certain situations is to insulate the cable ends and position them to avoid incidental contact, such as placing in a box. In this case, the cable ends are energized but inaccessible. Touching the cable at a damaged position remains dangerous. Checking for absence of voltage at the cable ends requires use of a suitable non-contact voltage measuring instrument (see B.5) or safe electrical practice, including hot gloves, to remove any insulation or open the isolation box and then measure with a contact instrument.

Figure I.5c: A preferred recommended practice prior to working with any exposed conductor (such as during splicing or cutting of the cable) is to short and ground the cable ends as part of a grounded equipotential zone. This will minimize the possibility of voltage occurring at the cable ends. Motor rotation may be detected by a suitable current measurement device without disconnecting the cable ends. Voltage along the cable from surface is limited to the voltage drop in the phase conductors caused by the phase current. As an example, an AWG 4 phase conductor has an approximate resistance of 0.25  $\Omega$  /1000 ft. At 50A current, the phase conductor to ground at 1000 ft from surface would be 12.5 V. Consequently, the risk from touching a damaged part of the cable is much reduced compared to contact with open phases. (The difference between the EMF and the cable voltage at the motor terminals is the voltage drop caused by the phase currents flowing through the motor winding impedance.)

The current and EMF from a shorted motor is supplied by power from the pump that rotates the shaft. Absorbing power from the pump in this way is braking action. This will limit the pump speed and thus the motor EMF compared to open phases, resulting in a further reduction in voltage along the cable.

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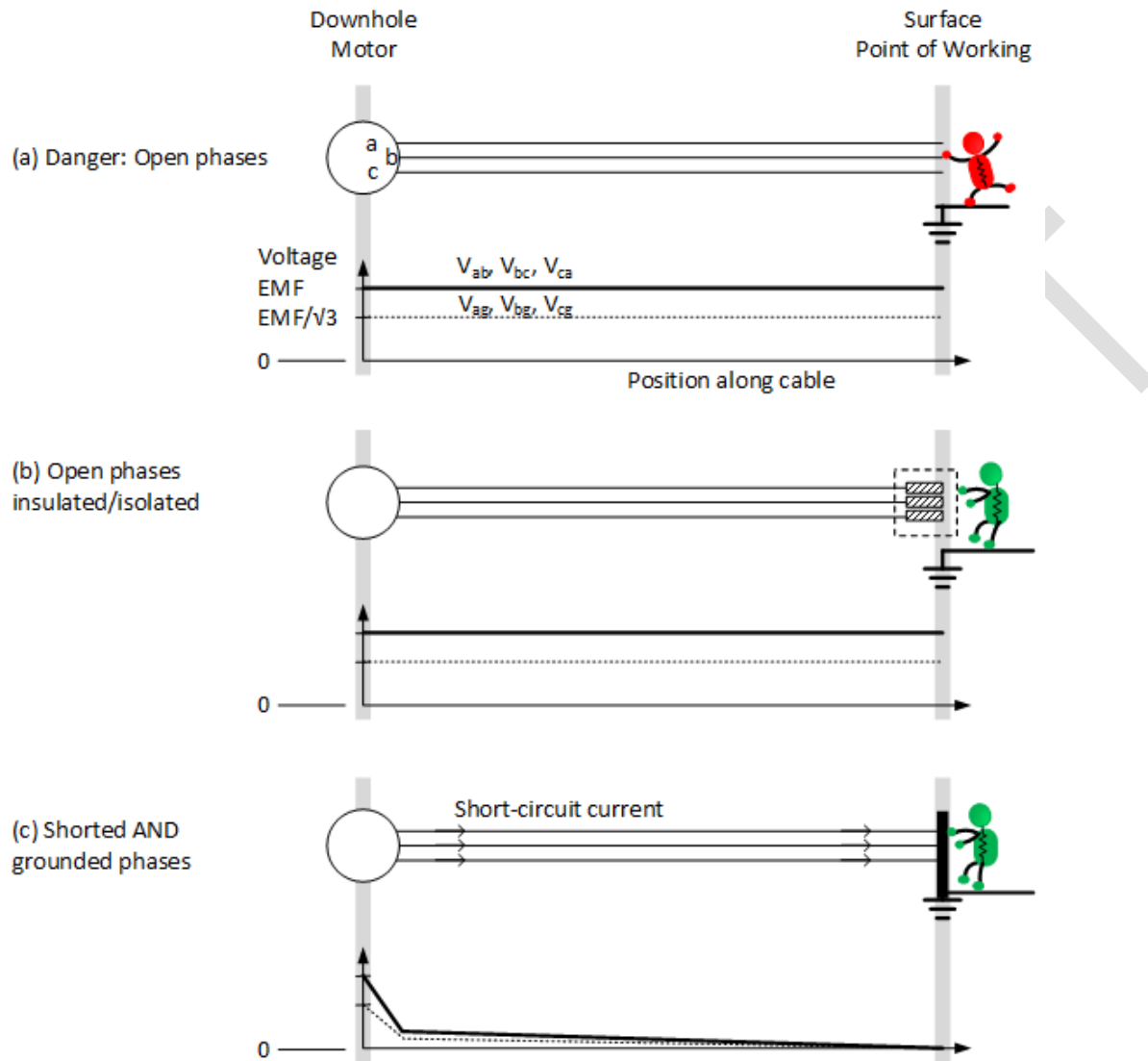


Figure I.5—Normal operation - voltages along cable.

#### I.4.2 Damaged installation

Figure I.6 shows a few examples of hazards that can arise when installations are damaged, or the cable ends are not properly terminated.

The recommended practice to ground and short all conductors as in Figure I.6c addresses these hazards for the conditions shown,



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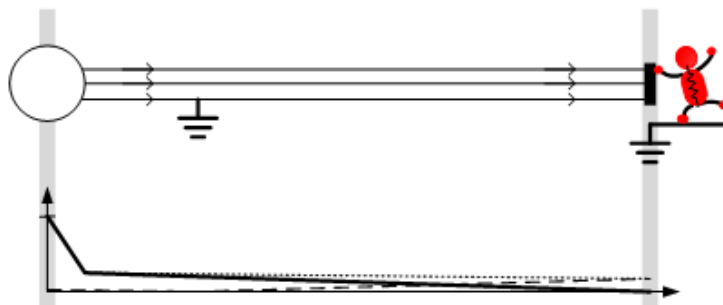
Figure I.6a: Cable ends shorted but not grounded, with a downhole ground fault near the motor. The phase-to-phase voltages remain the same as in a shorted and grounded system. The hazard that arises is that current in the grounded phase causes a voltage drop in the phase, which in turn results in voltage between the short and the ground.

Taking the above example cable, a ground fault at 10,000 ft will create 125 volts to ground at the short. This is a hazardous voltage and emphasizes the need for proper PPE to be worn when contact with the conductors is required. When measurements are not being taken, the short should be protected from incidental contact. As stated previously, if the conductors are found to be energized, work on the conductors is to cease until the conductors are no longer energized.

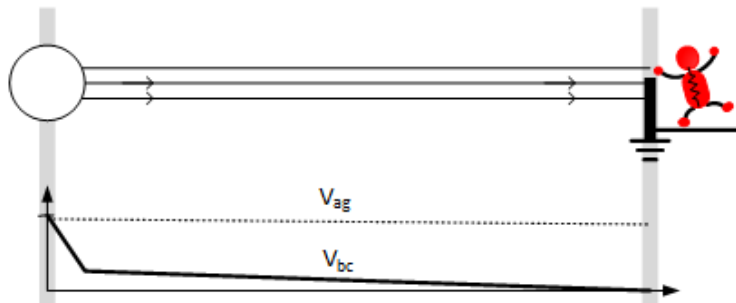
Figure I.6b: Two cable ends shorted and grounded, and the other left open. The voltage of the shorted phases is at ground potential at surface, rising slowly until the motor is reached, where the voltage to ground is the cable voltage drop due to the phase current. This current provides a braking action which will typically reduce the motor speed and EMF. However, the voltage difference between the open phase and the shorted phases is approximately 0.87 times the EMF. This will result in hazardous voltage at surface on the open phase unless the motor is turning very slowly.

Figure I.6c: All the phase conductors shorted together at surface. On phase C there is a ground fault and broken connection near the motor. There is no current flowing in phase C but it is grounded. Consequently, the remaining phase voltages are lifted from ground to the same voltage as in case (b), which is approximately 0.87 times the EMF.

(a) Danger: Shorted phases with downhole ground fault. (Dashed line is phase to ground voltage of the grounded phase and dotted line is the phase to ground voltage of the remaining phases.)



(b) Danger: Two phases shorted and grounded.



(c) Danger: Shorted phases with downhole ground fault and broken connection.

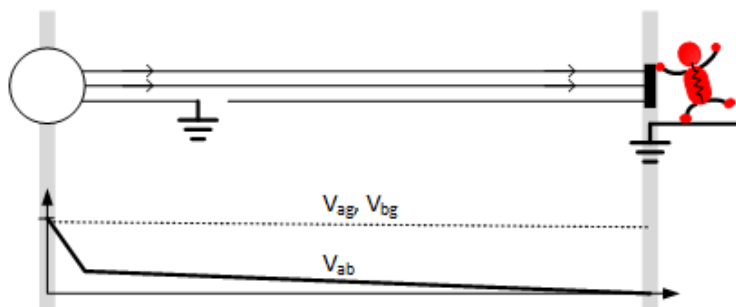


Figure I.6—Hazardous situations - voltages along cable.

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## **Annex J. (informative) Variable speed drives**

VSDs come in low voltage and medium voltage drive classifications wherein national and international standards have different voltage classifications for power distribution. Low voltage is less than or equal to 600V (NEC) and 1000V (IEC). Low voltage drives typically require an output step-up transformer and are the representative type in this document.

User settable controls are usually offered to set electrical frequency or to regulate motor speed, motor current or a process variable such as intake pressure. The drive will then dynamically adjust its electrical outputs – frequency and voltage or current – to maintain regulation. This mixture of controlled outputs and process variables has led to a wide range of synonyms for drives which are chosen by custom and practice according to the intended use. In general industry, "drive" is the typical term used to cover all the range of these devices.

Drive internal control algorithms generally are scalar or vector. Scalar drives output a voltage related to the frequency, without any specific knowledge of the motor, and specifically no information on instantaneous rotor position relative to the stator poles. In the oil industry, scalar control is almost universally used for IMs, as rotor position is not needed since IMs are asynchronous and inherently adjust their rotor position for optimum performance. Vector control methods almost all estimate and control the rotor position. This is potentially advantageous for synchronous motors like PMMs which do not inherently adjust their rotor position for optimum performance.

Flux control is a term sometimes used in the context of vector control methods and refers to regulating the strength of rotor poles in an IM (field weakening) and to adjusting power factor of a PMM. This can alter the motor performance for specific purposes.

Early submersible pumping systems that ran directly from 50/60 Hz utility supplies via a switchboard. This is scalar control with the voltage to frequency ratio equal to the utility voltage divided by utility frequency. When scalar drives were introduced, the operator entered the required frequency and the drive automatically changed the voltage as well, to maintain the voltage to frequency ratio.

Setting the frequency has become embedded in field practice. The great majority of IMs used for submersible pumping are two-pole. As an IM is asynchronous, 60 Hz electrical frequency typically corresponds to approximately 3500rpm, which is approximately 58 Hz shaft rotation frequency.

PMMs are synchronous machines, and the shaft rotation frequency is exactly proportional to the set electrical frequency. With a two pole PMM, setting 60 Hz electrical frequency is the same as setting 3600 rpm.

However, in many cases PMMs have more than two poles, and the relationship between electrical frequency and shaft speed (shaft rotation frequency) can confuse the uninitiated. A four pole PMM operating at 3600 rpm has a shaft rotation frequency of 60 Hz, but an electrical frequency of 120 Hz, as would be measured at the drive output.

Some VSDs will ask the user to enter the shaft rotation frequency or speed, but others may ask the user to enter the electrical frequency. The user must establish what the required type of input is, and know the motor pole count.

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## **Annex K. (informative) Mitigation techniques**

This Annex provides illustrations of devices currently in use for the mitigation of PMM risks. Figures K.1 through K.7 are for information only and are not referenced elsewhere in the document.

### **K.1 Passive components**

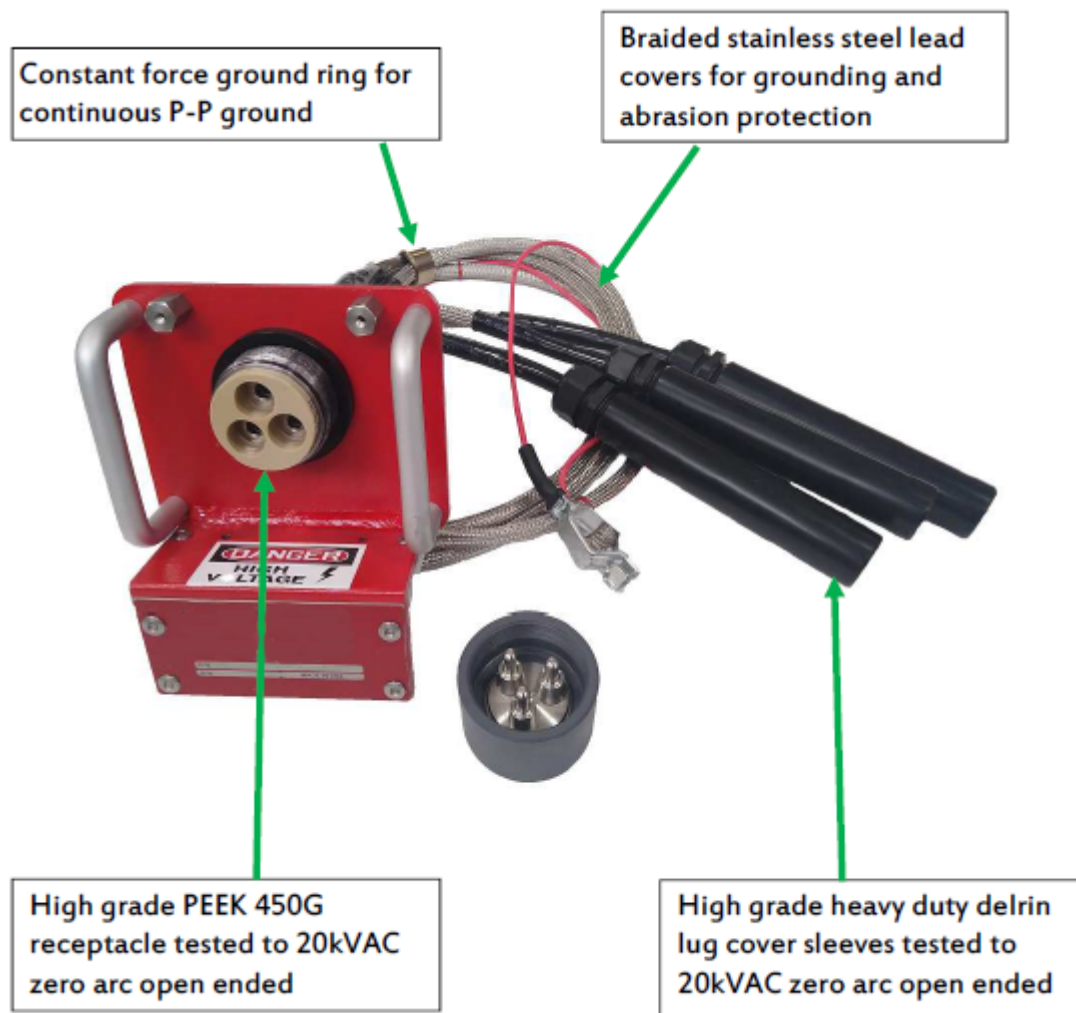
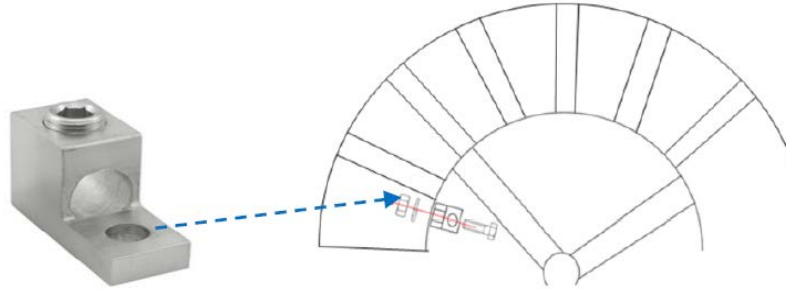


Figure K.1—Reel-mounted device for PMM cable.

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a) Shorting/grounding shunt



b) Spooler reel grounding lug



c) Cable insulation piercing clamps



d) Generic shorting grounding lug which come in variety



e) Plug Lockout Device

Figure K.2—Shorting and grounding components.

- **Rotary Grounding Assembly** provides a continuous connection between **Stationary Earth Ground Wire** and spooler axle. Centralizing adapter kits are available if needed
- **Axle Clamp** connects grounded axle to Test Stand inside the reel, out of the way of the spooler-reel interface
- **Test Stand** group ties, secures, and positions **Individual Conductor Legs** for adapting to different **Monitoring Methods** (to be supplied by PMM Operator)
- **Test Stand** also allows for easy connection/disconnection to the group tie/ground path, to allow isolation of individual legs for motor testing
- **Cable Connection Adapters** are available for either Pre-Installed Electrical Feedthrus or ESP Cable Legs to the **Individual Conductor Legs**
- **Stationary Earth Ground Wire** also provides \*Additional Monitoring Location\* outside the cable reel for reading while reel rotates

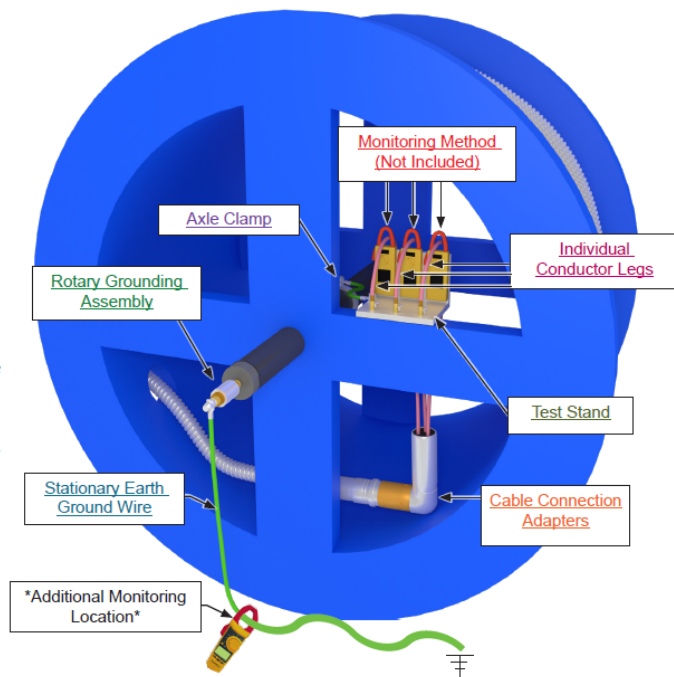


Figure K.3—Spooler continuous grounding system.

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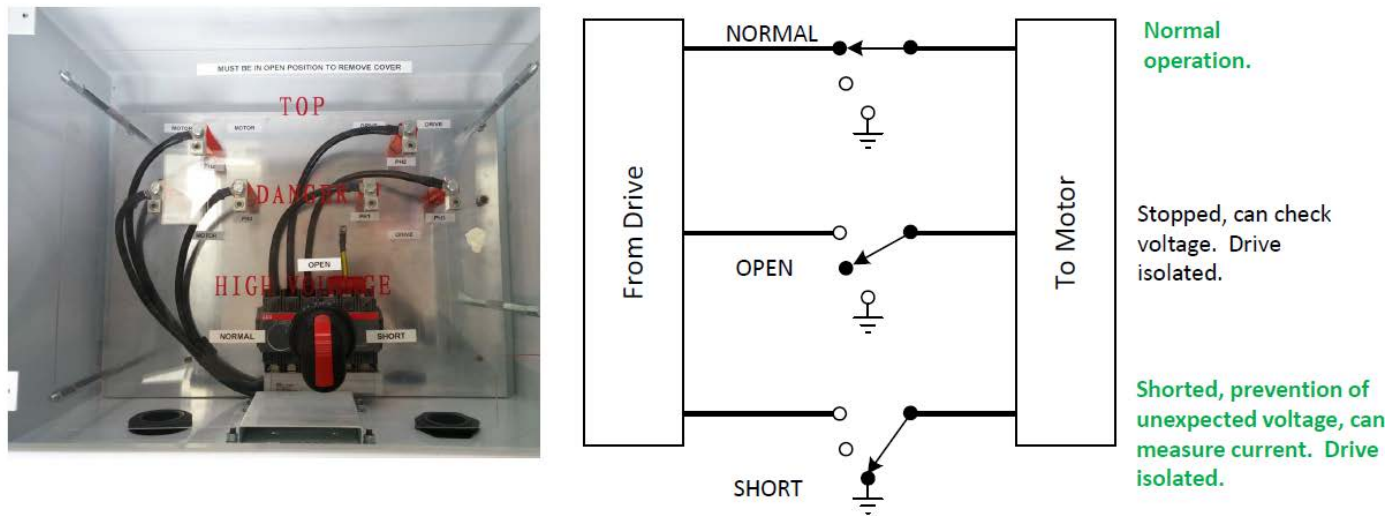


Figure K.4—Grounding and isolation switch for downhole-PMM driven PCP systems.

## K.2 Active components



Figure K.5—Continuous monitoring shorting and grounding for spooler and splicing.



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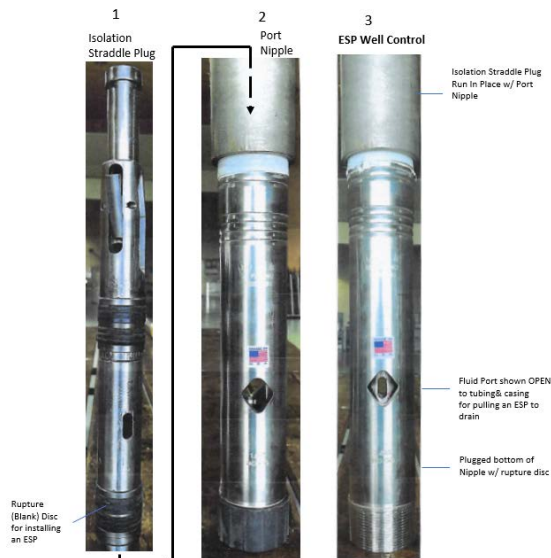
### K.3 PPE usage

NFPA 70E Cat1 or Cat2 worker at a VSD JB, and worker with voltage safety stick at spool reel



Figure K.6—PPE usage and volt stick at shunt.

### K.4 Well Control Tools



a) ESP well control



b) wireline insert with rupture disc

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(c) Sliding Sleeve installed with insert packer below

Figure K.7—Well Control Tools



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BALLOT DRAFT

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