



Electrical Submersible Pumps Manual

Design, Operations,
and Maintenance

Second Edition

Gabor Takacs



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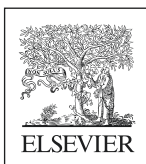
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Contents

Preface to the First Edition	xv
Preface to the Second Edition	xvii

1. Introduction

1.1 Artificial Lifting	1
1.1.1 Gas Lifting	1
1.1.2 Pumping	2
1.1.3 Comparison of Lift Methods	3
1.1.3.1 Lifting Capacities	3
1.1.3.2 System Efficiencies	5
1.1.3.3 Further Considerations	6
1.2 Short History of Electrical Submersible Pumping Applications	6
1.3 Basic Features of Electric Submersible Pumping Installations	8
1.3.1 Applications	8
1.3.2 Advantages and Limitations	9
References	10

2. Review of Fundamentals

2.1 Introduction	11
2.2 Well Inflow Performance	11
2.2.1 Introduction	11
2.2.2 The Productivity Index Concept	12
2.2.3 Inflow Performance Relationships	14
2.2.3.1 Introduction	14
2.2.3.2 Vogel's Inflow Performance Relationship	15
2.2.3.3 The Composite Inflow Performance	16
Relationship Curve	16
2.3 Hydraulic Fundamentals	21
2.3.1 Tubing Flow Calculations	21
2.3.2 Electrical Submersible Pumps	23
2.3.2.1 Operational Basics of Centrifugal Pumps	23
2.3.2.2 Specific Speed	27
2.3.2.3 Pump Performance	28
2.3.2.4 Cavitation	31
2.3.2.5 Axial Thrust Forces	32
2.3.2.6 Affinity Laws	34

2.4	Electrical Fundamentals	38
2.4.1	Alternating Current	38
2.4.2	Alternating Current Circuits, Alternating Current Power	40
2.4.3	Transformers	42
2.4.4	Electric Motors	44
	2.4.4.1 Induction Motors	44
	2.4.4.2 Permanent Magnet Motors	45
2.4.5	Electric Cable	47
2.5	Basics of Systems Analysis	48
2.5.1	Introduction	48
2.5.2	The Production System	49
2.5.3	Basic Principles	51
	References	52
3.	Electrical Submersible Pump Components and Their Operational Features	
3.1	Introduction	55
3.2	The Submersible Pump	57
3.2.1	Basic Features	57
	3.2.1.1 Pump Performance Curves	59
3.2.2	Floating Versus Fixed Impeller Pumps	65
3.2.3	Pump Temperature	67
3.2.4	Novel Pump Stage Design and Manufacturing	69
3.3	The ESP Motor	72
3.3.1	Induction-Type Asynchronous Motors	72
	3.3.1.1 Motor Construction	72
	3.3.1.2 Operational Features	80
	3.3.1.3 Motor Performance	81
	3.3.1.3.1 Motor Testing	82
	3.3.1.3.2 Performance Curves	83
	3.3.1.3.3 Startup Conditions	84
	3.3.1.4 Motor Temperature	87
	3.3.1.4.1 Heat Transfer Calculations	89
	3.3.1.4.2 Allowed Motor Temperature	96
	3.3.1.5 High-Performance Motors	97
3.3.2	Permanent Magnet Motors	98
	3.3.2.1 Introduction	98
	3.3.2.2 Motor Controllers for Permanent Magnet Motors	98
	3.3.2.2.1 Scalar Control	99
	3.3.2.2.2 Vector Control	102
	3.3.2.3 Constructional Details	103
	3.3.2.4 Operational Features	105
	3.3.2.5 Ultrahigh Speed Permanent Magnet Motor Applications	109
	3.3.2.6 Comparison with Induction Motors	111
	3.3.2.7 Case Studies	115
	3.3.2.8 Conclusions	116

3.4	The Protector or Seal Section	118
3.4.1	Main Functions	118
3.4.2	Basic Operation	119
3.4.3	Main Parts	121
3.4.3.1	The Thrust Bearing	121
3.4.3.2	Isolation Chambers	123
3.4.3.2.1	Labyrinth-Type Chambers	124
3.4.3.2.2	Blocking Fluids	126
3.4.3.2.3	Bag-Type Chambers	127
3.4.3.2.4	Metal Bellows Type Chambers	128
3.4.3.3	Shaft Seals	129
3.4.4	Other Features	130
3.5	The Gravitational Gas Separator	132
3.6	The ESP Cable	134
3.6.1	Cable Materials	134
3.6.2	Cable Construction	137
3.6.3	Operational Features	137
3.7	Miscellaneous Downhole Equipment	142
3.8	Surface Equipment	145
3.8.1	Wellhead	145
3.8.2	Junction Box	146
3.8.3	Switchboard	148
3.8.4	Transformers	149
3.8.5	Miscellaneous Equipment	149
	References	149
4.	Use of ESP Equipment in Special Conditions	
4.1	Introduction	153
4.2	Pumping Viscous Liquids	153
4.2.1	Introduction	153
4.2.2	The Hydraulic Institute Model	154
4.2.3	Other Models	159
4.3	Low or Changing Pumping Rates	162
4.3.1	Low-Rate Pumps	162
4.3.2	Wide-Operating-Range Pumps	163
4.4	Production of Gassy Wells	164
4.4.1	Introduction	164
4.4.2	Free-Gas Volume Calculations	165
4.4.3	Pump Performance Degradation	172
4.4.3.1	Gas Interference in Centrifugal Pumps	172
4.4.3.2	Performance Criteria	175
4.4.4	Possible Solutions	177
4.4.4.1	Utilization of Natural Gas Separation	177
4.4.4.1.1	Pump Set Below the Perforations	177
4.4.4.1.2	Use of Motor Shrouds	178

4.4.4.2	Rotary Gas Separators	182
4.4.4.2.1	Available Types	182
4.4.4.2.2	The Role of Inducers	184
4.4.4.2.3	Separation Efficiencies	186
4.4.4.3	Gas Handling	189
4.4.4.3.1	Legacy Methods	189
4.4.4.3.2	Modern Solutions	191
4.4.5	Conclusions	194
4.5	Production of Abrasive Solids	195
4.5.1	Conventional Pumps	195
4.5.1.1	Introduction	195
4.5.1.2	Characteristics of Abrasive Materials	196
4.5.1.3	Sand Problem Areas	198
4.5.1.3.1	Pump Erosion	199
4.5.1.3.2	Abrasion in Radial Bearings	199
4.5.1.3.3	Abrasion in Thrust Washers	200
4.5.1.4	Solutions	200
4.5.1.4.1	Reduction of Radial Wear	201
4.5.1.5	Preventing Sand Accumulation Above the Pump	205
4.5.1.6	Conclusions	206
4.5.2	Special Pumps for Abrasive Handling	207
4.6	High Well Temperatures	210
4.6.1	Temperature Problems and Solutions	210
4.6.2	Geothermal, Steam-Assisted Gravity Drainage Applications	213
4.7	Variable-Frequency Operation	214
4.7.1	Pump Performance at Variable Speeds	214
4.7.2	Variable-Speed Drives	217
4.7.2.1	Constructional Details	218
4.7.2.1.1	The Rectifier	218
4.7.2.1.2	The Direct Current Control Section	219
4.7.2.1.3	The Inverter	219
4.7.2.2	Available Variable-Speed Drive Types	220
4.7.2.2.1	“Six-Step” Variable-Speed Drive	220
4.7.2.2.2	Pulsed Width Modulation	220
4.7.2.2.3	Sine Wave Generators	223
4.7.2.2.4	Vector Control Devices	223
4.7.2.3	Operational Characteristics	224
4.7.3	Variable-Frequency Generators	225
4.7.4	Interaction of VSD/VFG and ESP Units	226
4.7.4.1	Variable-Frequency Operation of Electrical Motors	226
4.7.4.2	Interaction of ESP Motors and VSD/VFG Units	230

4.7.5	Benefits of Using Variable-Speed Drive/Variable-Frequency Generator Units	233
4.8	Other Problems	235
	References	236

5. Design of ESP Installations

5.1	Introduction	241
5.2	Data Requirements	241
5.3	Conventional Design	242
5.3.1	Well Inflow Calculations	243
5.3.2	Total Dynamic Head Calculations	245
5.3.3	Selection of the Pump	246
5.3.3.1	Pump Series	246
5.3.3.2	Pump Type	247
5.3.3.3	Number of Stages, Pump Power	247
5.3.3.4	Checking the Pump's Mechanical Strength	250
5.3.4	Selection of the Protector	250
5.3.5	Motor Selection	253
5.3.6	Selection of the Power Cable	255
5.3.6.1	Cable Length	256
5.3.6.2	Cable Type	256
5.3.6.3	Cable Size	256
5.3.6.4	Checking Motor Startup	259
5.3.7	Switchboard and Transformer Selection	259
5.3.8	Miscellaneous Equipment	260
5.3.8.1	Downhole Equipment	260
5.3.8.2	Surface Equipment	260
5.4	Conventional Design Considering Motor Slip	266
5.4.1	Introduction	266
5.4.2	Interaction of the ESP Motor and the Pump	267
5.4.3	Changes in the Conventional Design	269
5.4.3.1	Finding Actual Motor Speed	269
5.4.3.2	Finding Pump Head Including Motor Slip	269
5.5	Gassy Well Design	272
5.5.1	Inflow and Free Gas Calculations	273
5.5.2	Calculation of Total Dynamic Head	274
5.5.3	The Rest of the Design Procedure	276
5.6	Design of a Variable Speed Drive Installation	283
5.6.1	Introduction	283
5.6.2	Pump Selection for Variable Speed Drive Service	284
5.6.2.1	Driving Frequency and the Number of Stages	284
5.6.2.2	Checking Pump Operation at the Minimum Liquid Rate	285
5.6.3	Motor Selection	285
5.6.4	Switchboard and Transformers	287

5.7	Design of a Permanent Magnet Motor Installation	297
5.7.1	Design Considerations	297
5.7.1.1	Selection of the Pump	297
5.7.1.2	Selection of the Permanent Magnet Motor	300
5.8	Comparison of Induction Motor and Permanent Magnet Motor Installations	304
	References	305
6.	Analysis and Optimization	307
6.1	Introduction	307
6.2	NODAL Analysis	307
6.2.1	Using the Head—Rate Coordinate System	309
6.2.1.1	Single-Phase Cases	310
6.2.1.1.1	Constant Pumping Speed	312
6.2.1.1.2	Variable Pumping Speeds	315
6.2.1.1.3	Variable Wellhead Pressures	316
6.2.1.2	Multiphase Cases	318
6.2.1.2.1	Calculation Model	320
6.2.1.2.2	Applications	323
6.2.2	Using the Pressure—Rate Coordinate System	327
6.2.2.1	Single-Phase Cases	329
6.2.2.2	Multiphase Cases	334
6.3	Determination of Well Inflow Performance	336
6.3.1	The Conventional Method	336
6.3.2	Use of Variable-Speed Drives	339
6.3.3	Calculation of Bottomhole Pressures	341
6.3.3.1	Introduction	341
6.3.3.2	Annular Liquid Gradients	342
6.3.3.2.1	Static Conditions	343
6.3.3.2.2	Flowing Conditions	344
6.4	Power Efficiency of ESP Installations	348
6.4.1	Power Flow in the ESP System	349
6.4.2	Energy Losses and Efficiencies	351
6.4.2.1	Hydraulic Losses	352
6.4.2.1.1	Tubing Losses	352
6.4.2.1.2	Backpressure Losses	353
6.4.2.1.3	Pump Losses	354
6.4.2.1.4	Power Loss in Gas Separator	354
6.4.2.2	Electrical Losses	354
6.4.2.2.1	Motor Losses	355
6.4.2.2.2	Cable Losses	355
6.4.2.2.3	Surface Electrical Losses	356
6.4.3	System Efficiency	356
6.5	Optimization of Electrical Submersible Pump Operations	360
6.5.1	Introduction	360
6.5.2	Basics of Economic Optimization	361
	References	365

7.	Operation, Monitoring, and Surveillance of Electrical Submersible Pumping Systems	
7.1	Introduction	367
7.2	Guidelines for Running and Pulling	367
7.2.1	Transportation to the Wellsite	368
7.2.2	Equipment Installation	368
7.2.2.1	Motor Installation	368
7.2.2.2	Protector Installation	369
7.2.2.3	Pump Installation	369
7.2.2.4	ESP Cable Installation	370
7.2.2.5	Final Measures	370
7.2.3	Running Equipment in the Well	370
7.2.4	System Startup	371
7.2.5	Pulling ESP Equipment	372
7.3	Production Control	373
7.3.1	Introduction	373
7.3.2	The Effects of Using Wellhead Chokes	374
7.3.2.1	The Need for Wellhead Chokes	374
7.3.2.2	Use of Variable-Speed Drive Units	377
7.3.2.3	Sample Calculations	378
7.4	Monitoring ESP Operations	383
7.4.1	Introduction	383
7.4.2	Acoustic Surveys	386
7.4.3	Downhole Measurements	387
7.4.3.1	Instruments and Communications	388
7.4.3.2	Measured Parameters and Their Use	389
7.4.4	Surface Controllers	390
7.4.4.1	Introduction	390
7.4.4.1.1	Fixed-Speed Drives	390
7.4.4.1.2	Variable-Speed Drives	390
7.4.4.2	ESP Controller Functions	391
7.5	Surveillance of ESP Operations	391
7.5.1	Introduction	391
7.5.2	Key Challenges and Requirements in Production Operations	393
7.5.3	The Digital Oilfield	394
7.5.3.1	An Overview	394
7.5.3.2	Digital Oilfield: Step-by-Step Progression	396
7.5.4	ESP Data Visualization	398
7.5.4.1	Well Status and Well Group Status	398
7.5.4.2	Analysis Using Data Trend Visualization	401
	References	404
8.	Failures and Troubleshooting	
8.1	Introduction	405
8.2	System Failures	405

8.2.1	General Causes of Failures	405
8.2.1.1	Vibrations in the ESP System	407
8.2.2	Typical Failures of System Components	409
8.2.3	ESP Teardown Analysis	411
8.2.3.1	Introduction	411
8.2.3.2	General Considerations	412
8.2.3.3	Motor Inspection	413
8.2.3.4	Protector Inspection	415
8.2.3.5	Pump Inspection	416
8.2.3.6	Cable Inspection	418
8.2.3.7	Inspection of Other Equipment	418
8.2.4	Failure Tracking	419
8.2.5	Run-Life Estimation	420
8.2.5.1	Introduction	420
8.2.5.2	Run-Life Measures	421
8.2.5.3	Lifetime Distribution	424
8.3	Troubleshooting Electrical Submersible Pumping Installations	425
8.3.1	Interpretation of Ammeter Charts	425
8.3.2	Nodal Analysis Techniques	440
8.3.2.1	Introduction	440
8.3.2.2	Applications	440
8.3.2.3	The Use of Measured Pump Intake and Discharge Pressures	443
	References	447

9. Special Installations

9.1	Introduction	449
9.2	Tubing Deployed Installations	449
9.2.1	Producing a Single Zone	449
9.2.1.1	Shrouded and Horizontal Well Installations	449
9.2.1.2	Parallely Connected Installations	450
9.2.1.3	Series-Connected Installations	451
9.2.2	Dual Zone Installations	453
9.2.2.1	Production Commingling	453
9.2.2.2	Selective Production	455
9.3	Alternative Deployed Installations	456
9.3.1	Cable Suspended Units	457
9.3.2	Coiled Tubing Installations	458
9.3.2.1	Cable Led Outside the Coiled Tubing String	458
9.3.2.2	Cable Led Inside the Coiled Tubing String	460
9.3.3	Thru-Tubing Deployed Systems	462
9.3.3.1	Retrievable ESP Pumps	462
9.3.3.2	Retrievable ESP Systems	464
9.3.4	Conclusions	467

9.4	Horizontal Pumping Systems	468
9.4.1	Available Configurations	468
9.4.2	Typical Applications	469
	References	469
Appendices		471
Class Problems		497
Index		545

(VSDs) are used. Utilization of VSD units in such cases eliminates the need to exchange the pump to one for which operating range covers the well's required liquid rate.

Example 2.5

The BEP of one stage of a centrifugal pump is at a rate of 1,200 bpd, where the head is 52 ft, and the required brake horsepower is 1 HP. The pump operates at a speed of 3,500 RPM (60 Hz service); find its parameters at 50 Hz for a speed of 2,917 RPM.

Solution

The new rate at the new speed is found from Eq. (2.17):

$$Q_2 = 1,200(2,917/3,500) = 1,000 \text{ bpd.}$$

The new head and brake horsepower are calculated from Eqs. (2.18) and (2.19), respectively:

$$H_2 = 52(2,917/3,500)^2 = 36 \text{ ft.}$$

$$BHP_2 = 1(2,917/3,500)^3 = 0.6 \text{ HP.}$$

Using electrical frequency instead of pumping speed in the **affinity law** formulas, the calculations are as follows:

The new rate at the new frequency is found as:

$$Q_2 = 1,200(50/60) = 1,000 \text{ bpd.}$$

The new head and brake horsepower are calculated:

$$H_2 = 52(50/60)^2 = 36 \text{ ft.}$$

$$BHP_2 = 1(50/60)^3 = 0.6 \text{ HP.}$$

As seen, the results are identical.

The **affinity laws** permit the creation of pump performance curves at any rotational speed from curves known at a given speed. When converting the **head** performance curve (the most important parameter of the centrifugal pump) from one pumping speed to another, combination of Eqs. (2.17) and (18) results in the following formula:

$$H_2 = H_1 \left(\frac{Q_2}{Q_1} \right)^2 \quad (2.20)$$

Because the values H_1 and Q_1 are constant, the formula can be modified to:

$$H_2 = k Q_2^2 \quad (2.21)$$

where:

H_2 = developed head at N_2 , ft

Q_2 = pumping rate at N_2 , bpd

k = constant found from Eq. (2.20)

The plot of this function in the H versus Q coordinate system is a second-order **parabola** started from the origin and running through the H_1 – Q_1 point valid for the original speed. Many such curves can be constructed, and they are called “**affine parabolas**”; they connect the corresponding operating points on the head performance curves that belong to the different speeds. The “tornado curve” presented in Fig. 2.19 contains these curves, which, in addition to the just described feature, represent constant pump efficiencies.

If the operation of centrifugal pumps with different impeller sizes is compared at different pumping speeds, the **affinity** laws are modified and include the impeller diameters as well. As before, instead of the pumping speeds also the electrical frequencies can be used in the formulas given here.

$$Q_2 = Q_1 \left(\frac{N_2}{N_1} \right) \left(\frac{d_2}{d_1} \right) \quad (2.22)$$

$$H_2 = H_1 \left(\frac{N_2}{N_1} \right)^2 \left(\frac{d_2}{d_1} \right)^2 \quad (2.23)$$

$$BHP_2 = BHP_1 \left(\frac{N_2}{N_1} \right)^3 \left(\frac{d_2}{d_1} \right)^3 \quad (2.24)$$

where:

N_2, N_1 = pumping speeds, RPM

Q_2, Q_1 = pumping rates at N_2 and N_1 , bpd

H_2, H_1 = developed heads at N_2 and N_1 , ft

d_2, d_1 = impeller diameters, in

BHP_2, BHP_1 = required brake horsepowers at N_2 and N_1 , HP

2.4 ELECTRICAL FUNDAMENTALS

2.4.1 Alternating Current

Most electric motors used to drive ESP installations are AC (alternating current) motors, i.e., they rely on a supply of alternating electric voltage. Alternating voltage or AC reverses its direction from positive to negative and alternates between constant positive and negative values. In contrast to direct current, AC permits the use of **transformers** to change its voltage to any desired level. This feature is exploited in long-distance **transmission** of electric power when the voltage of the generated electricity is raised to very high values, thus effectively reducing the size of the required transmission wires and the power losses occurring. At the consumer end, another transformer is used to reduce the high voltage to the desired value before it is used.

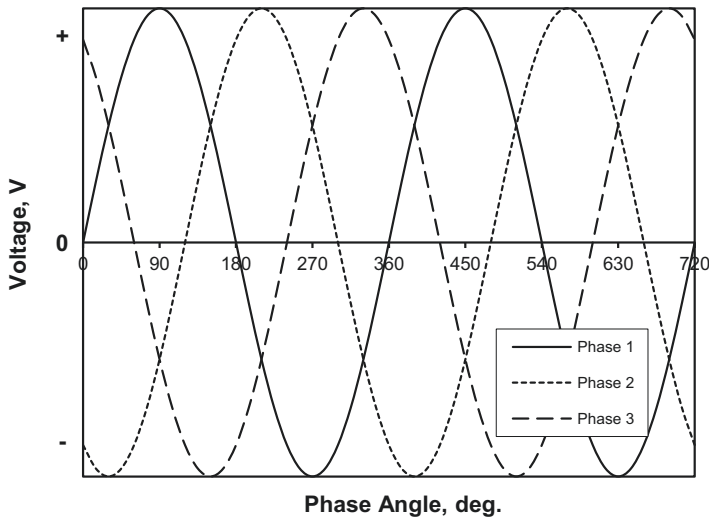


FIGURE 2.20 Change of line voltages in three-phase alternating current (AC) circuits.

Motors of greater power capacity are usually driven by **three-phase** electric supplies, each phase having its alternating voltage and current pattern. Voltage and current in each phase change according to **sine curves**, as shown in Fig. 2.20, and are shifted from each other by one-third of the cycle time. In one full cycle (360 degrees in the figure) the direction of the current changes two times; the number of cycles per one second is called the **frequency** of the electricity, with usual values of 60 or 50 Hz. The change in voltage, for example, with time can be expressed with the following formula:

$$V = V_{\max} \sin(2\pi ft) \quad (2.25)$$

where:

V = voltage, Volts

$V_{\max}$ = maximum value or amplitude, Volts

f = frequency, Hz

t = time, s

The flow of an AC in a wire or any other equipment involves **energy losses** dissipated as **heat**, independent of the direction of the current. To calculate these losses, the **effective current** is introduced, which represents the heating effect of the current and is calculated as the **root mean square** (rms) value defined as follows:

$$I_{\text{eff}} = \sqrt{\frac{1}{T} \int_0^T I^2 dt} = \frac{I_{\max}}{\sqrt{2}} = 0.707 I_{\max} \quad (2.26)$$

Chapter 3

Electrical Submersible Pump Components and Their Operational Features

3.1 INTRODUCTION

During its long history, the electrical submersible pump (ESP) system proved to be an efficient means of producing liquid from oil and water wells. The classical or “**conventional**” installation is illustrated in Fig. 3.1, in which the ESP unit is run on the tubing string and is submerged in well fluids. The electric submersible **motor** is at the bottom of the unit and is cooled by the wellstream passing by its perimeter. It is connected to the **protector** (a.k.a. seal) section that provides many crucial functions for the safe operation of the unit. On top of the protector a pump intake or gas separator is situated, which allows well fluids to enter the centrifugal pump and, at the same time, can remove low quantities of free gas from the wellstream. The separated gas bubbles through the liquid column in the casing annulus and reaches the casinghead where it is directed into the flowline. Connection of the casinghead to the flowline ensures that the fluid level is kept constant above the submersible pump. Liquid is lifted to the surface by the **multistage centrifugal pump**, the heart of the ESP system.

The submersible motor is supplied with three-phase alternative current (AC) via an **electric cable** running from the surface all along the tubing string. Produced fluids flow through the tubing string to the surface, where a special **wellhead** ensures feeding of the electric cable into the well. The surface equipment includes a **junction box** where downhole and surface electric cables are joined and a control unit (called **switchboard**) that provides measurement and control functions. The ESP unit receives AC from a set of **transformers** (not shown) that supply the required voltage by stepping up or down the voltage available from the surface electric network.

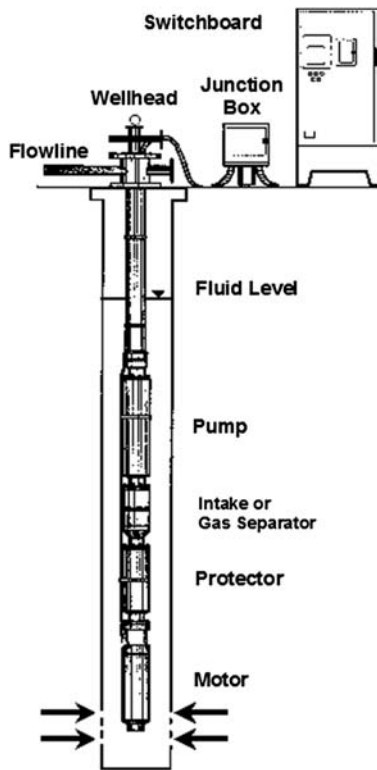


FIGURE 3.1 Conventional ESP installation.

The above type of installation has stood the test of time and is frequently used even today. The most important features making it a **conventional ESP installation** are as follows:

- Only **liquid** enters the centrifugal pump providing ideal conditions for the pump. The well must produce only a low amount of free gas at the pump suction that can easily be removed by the gas separator.
- The viscosity of the produced liquid is low, approaching the viscosity of water.
- The ESP motor is supplied with an AC of a **constant frequency**, thus its speed and consequently that of the centrifugal pump are constant.

Although the abovementioned conditions are not always met, the conventional ESP installation can be applied in a great variety of field conditions. This chapter will discuss the components of such conventional installations and also details their main operational features. Unusual conditions (greater gas production, viscous crude, etc.) require the use of special equipment; installations different from the conventional are the subject of Chapter 4.

connects to the motor's **pothead** ensures easier installation but usually is not as reliable as the taped splicing.

Single motors are available in different sizes, usually between ODs of 3"—8", with BHP ratings in a broad range. For use in a given well casing size, i.e., for a constant motor OD, power can be increased only by increasing the length of the motor and **tandem motors** made up of several (up to three) individual motors are also available.

Tandem motors are composed of two or three standard ESP motors mechanically coupled at their shafts and fed by a single power cable. They come in different versions: **upper tandem (UT)** motors have the pothead at their head for electric connections, while **center tandem** or **lower tandem** motors are used in conjunction with an **UT** motor and have internal electric connections. Tandem motors are connected in series electrically: their voltage requirement is the sum of the individual nameplate voltages and they receive the same nameplate current. The main **rule** in making tandem motors is to select motors with **identical** power and voltage ratings; the tandem's power and voltage are doubled, whereas its current remains the same. Total power of tandem motors can go up well over 1,000 HP.

One specific case utilizes two tandem motors independently connected to two surface supply systems having their individual power cables, see [Fig. 3.20](#).

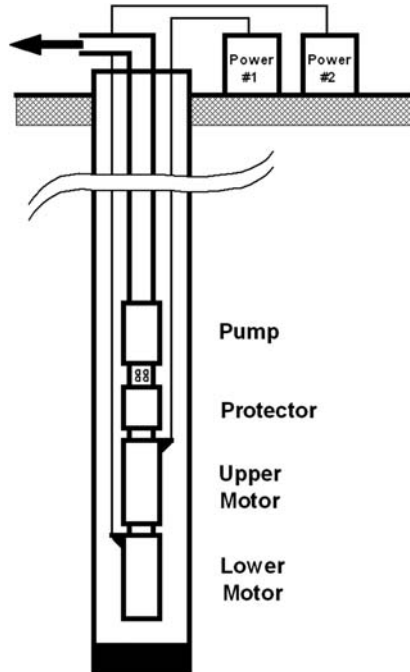


FIGURE 3.20 Two ESP motors connected parallelly to the power supply.

The two ESP motors are mechanically coupled (i.e., have their shafts connected to each other and to the rest of the downhole equipment) but work independently in an electric sense. As described in Ref. [13], motor power was reliably increased to 2,000 HP, allowing the production of 30,000 bpd liquid from several installations.

This solution has many beneficial features as compared to the conventional tandem motors connected in series to the electric supply, including

- the use of **standard** size equipment components [variable-speed drive (VSD), cable, switchboard] is sufficient,
- standard equipment is usually **readily** available from manufacturers,
- investment costs are lower.

3.3.1.2 Operational Features

ESP motors are very different from electric motors in everyday use on the surface. The most important differences [14] are listed in the following, a basic comprehension of which is necessary to fully understand the operational features of ESP motors.

- As they must be run inside the well's casing string, their **length-to-diameter** ratio is much greater than that of surface motors.
- Motor power can only be increased by increasing the **length** of the unit.
- Surface motors are usually cooled by the surrounding air, whereas ESP motors are cooled by the convective **heat transfer** taking place in the well fluid flowing past the motor.
- Because of the great difference between the heat capacities of air and liquids and the accordingly higher cooling effect, electric current densities that are 10 times higher than those in surface motors can be used in ESP motors without severe overheating.
- ESP motors have exceptionally low **inertia** and accelerate to full speed in less than 0.2 s when starting.
- ESP motors are connected to their power source by **long** well cables, where a substantial voltage drop occurs.

Motors with the same nameplate horsepower are available in different **voltage** and **current** combinations, the reason being that electric power is defined as the product of those two parameters. Thus a motor with a low voltage requirement draws a higher current and vice versa; however, both may provide the same rated electric horsepower. This feature of electric motors enables the designer to choose the right motor for every installation, the objective being the selection of a motor with a voltage–current combination assuring the **most efficient use** of electric power.

Motor **rotation** should comply with the preferred rotation of the submersible **pump**; it can be **CCW** or **CW**, the motor works exactly perfect in

either direction. Rotational direction is set and checked at equipment installation and is easily changed by changing two of the connections of the motor terminals to the phases of the power source. CW rotation has the disadvantage that threaded connections in the pump, motor, and other equipment may get **unscrewed** during operation. This must be prevented by plates welded to the outside of equipment pieces; CCW rotation prevents such problems.

Operational data of two series of motors available from a leading manufacturer are listed in **Appendix D**.

3.3.1.3 Motor Performance

IMs used in ESP service have operational features very similar to **NEMA (National Electrical Manufacturers Association) B** electric motors. A schematic torque—speed performance curve is shown in Fig. 3.21, valid at a constant input voltage. The synchronous speed of the motor is the rotational speed of the magnetic field in the stator. At speeds higher than this the motor becomes a **generator**; motoring is restricted to speeds lower than N_{synch} .

Stable motor performance is restricted to speeds higher than the speed belonging to the maximum (**breakdown**) torque value. This is because the load on the motor increases with speed and a stable common operating point of the motor and the submersible pump can be achieved in this region only.

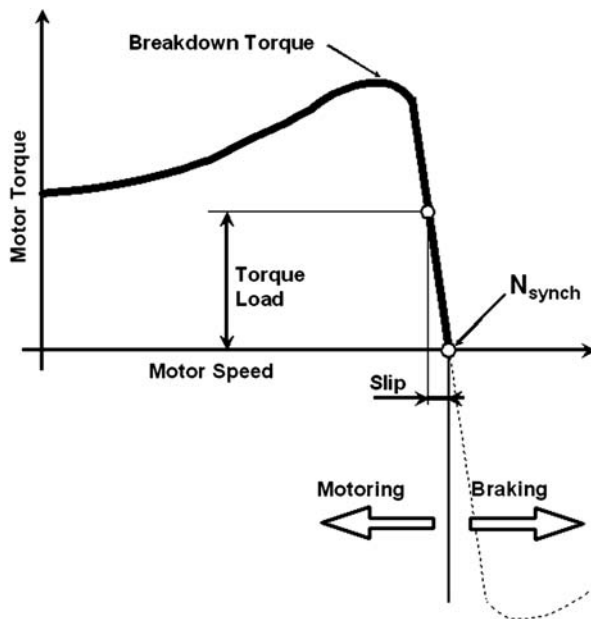


FIGURE 3.21 Typical torque—speed performance of an ESP motor at constant voltage.

with the tubing string, its steady-state temperature is the result of the following factors:

- ambient (**fluid**) temperature valid in the tubing string,
- the amount of heat **generated** in the cable due to the operating electric current,
- the amount of heat **dissipated** in the stagnant fluid (liquid or gas) present in the annulus.

Because of these effects, cable temperature changes along the tubing string in such a way that it **parallels** the tubing temperature but is always greater than that. The difference depends on the **balance** of the generated and dissipated heats. Heat is dissipated in the annulus by **natural convection**, the effectiveness of which greatly depends on the type of fluid filling the annular volume. This is why cable differential temperature is different **below** and above the dynamic liquid level in the annulus.

As natural convection is more efficient in liquids than in gases, the cable is cooled better **below** the dynamic liquid level than in the upper well sections where the annulus contains gas only. The depth of the annular liquid level, therefore, greatly affects the maximum temperature of the cable. With high liquid levels, maximum temperature occurs at the setting depth of the motor. On the other hand, if the liquid level is close to the depth of the motor, this is where maximum cable temperature may occur.

The electric **impedance** of the cable increases with temperature and the following formula is used to find the resistance (because inductive reactance is negligible) at elevated temperatures (see also Eq. 2.36):

$$R_T = \frac{L_c r}{1,000} [1 + 0.00214(T - 77)] \quad (3.23)$$

where

R_T = cable impedance at temperature T , ohms

L_c = cable length, ft

r = resistance of conductor at 77°F, ohm/1,000 ft

T = cable temperature, °F.

The **voltage drop** in cables is a very important parameter and defines the inevitable **energy losses** occurring in the cable because voltage drop multiplied by the current gives the electric energy wasted in the ESP cable. Voltage drop changes with the material, the size, and the temperature of the conductor but the main parameter is the magnitude of the current flowing in the cable. The following formula is used to find the three-phase voltage drop across the cable:

$$\Delta U_{\text{cable}} = \sqrt{3} R_T I = 1.732 R_T I \quad (3.24)$$

where

ΔU_{cable} = voltage drop in cable, V

R_T = cable impedance at temperature T , ohms

I = motor current, A.

TABLE 3.7 Typical Voltage Drops in Copper Conductors	
AWG	Voltage Drop per 1 A (V/1,000 ft at 20°C)
1	0.26
2	0.33
4	0.53
6	0.84
8	1.32

After Brown KE. The technology of artificial lift methods, vol. 2b. Tulsa, Oklahoma: PennWell Books; 1980.

Table 3.7 contains typical values of voltage drops in copper conductors for each 1,000 ft of cable length, assuming a current of 1 A [61].

Fig. E.1 in **Appendix E**, as given by most cable manufacturers, can be used to calculate the voltage drop in usual ESP cables. Because temperature has a direct effect on the electric resistance of metal wires, the values read from the figure must be corrected for elevated temperatures by using the correction factors given. The correction factors can also be calculated from Eq. (3.23) introduced earlier.

The three-phase **power loss** (in kilowatts) in the cable is calculated from the cable resistance and the motor current as follows:

$$\Delta P_c = \frac{3 I^2 R_T}{1,000} \tag{3.25}$$

where

- ΔP_c = power loss in cable, kW
- R_T = cable impedance at temperature T , ohms
- I = motor current, A.

Example 3.5

Calculate the voltage drop and the energy wasted in an **AWG 4** size 4,500-ft-long cable, if the average cable temperature is 350°F, the resistance of the conductor at 77°F is 0.271 Ω/1,000 ft, and motor current is 30 A.

Solution

The total resistance of the cable at the given temperature is found from Eq. (3.23) as

$$R_T = 4.5 \, 0.271 [1 + 0.00214(350 - 77)] = 1.22 \, 1.58 = 2.5 \, \Omega.$$

The prime factor in selecting the motor voltage is the running **depth** of the ESP unit because it heavily affects the **voltage drop** in the electric cable. Deeper installations require longer cables and involve higher voltage drops across the cable; this leads to greater amounts of **wasted** electrical energy and lower system efficiencies. In such conditions, selecting a motor with a higher voltage rating means that a much lower current flows through the cable causing a lower voltage drop; consequently, the amount of wasted power is reduced. In addition, the use of higher voltages is advantageous in **high-temperature** wells because higher voltage motors need less current to develop the same horsepower; thus the operating temperature of the electric cable is reduced, and cable life is increased.

Based on the considerations just discussed and an analysis of the power flow in the ESP system, **Powers [10]** concludes that in most situations the motor with the **highest** voltage requirement is the proper choice. This not only reduces the total power consumption but many times allows the use of a smaller and less expensive power cable.

Example 5.2

Select the proper 456 series motor for the conditions in [Example 5.1](#) and find its main parameters based on motor data at 60 Hz operation, given in Table D.1 in [Appendix D](#).

Solution

The required motor power at 50 Hz was calculated as 48 HP in the previous example. The corresponding motor power at 60 Hz is found from [Eq. \(5.19\)](#):

$$HP_{60} = 48 \cdot 60/50 = 58 \text{ HP.}$$

From Table D.1 the motor with the next higher power rating is chosen, its nameplate data are as follows:

$$NPHP_{60} = 72 \text{ HP, } NPV_{60} = 2,288 \text{ Volts, } NP \text{ Amps}_{60} = 20 \text{ Amps.}$$

The motor's nameplate power at 50 Hz is expressed from [Eq. \(5.19\)](#):

$$NPHP_{50} = 72 \cdot 50/60 = 60 \text{ HP.}$$

Motor nameplate voltage at 50 Hz operation is found from [Eq. \(5.20\)](#):

$$U_{np} = 2,288 \cdot 50/60 = 1,907 \text{ Volts.}$$

Current demand of the motor is calculated from [Eq. \(5.21\)](#):

$$I = 20 \cdot 48/60 = 16 \text{ Amps.}$$

5.3.6 Selection of the Power Cable

The electric power cable is a **vital** part and usually is the most **expensive** item of the ESP system. Its proper selection is not only a technical task but requires,

as it will be shown later, **economic** considerations as well. Cable for the ESP industry is manufactured in a wide variety of types, sizes, etc. When designing an ESP installation, the right cable is selected by determining its required (1) **length**, (2) **type**, and (3) **size**, with proper considerations of all operational conditions.

5.3.6.1 Cable Length

The length of the power cable is determined from the running depth of the motor to which a sufficient length needed for the safe connection of surface equipment (about 100 ft) is added. The **main** cable (usually a round configuration) should reach down to the top of the ESP unit from where a motor lead **extension** (MLE: usually a flat cable section) runs to the **pothead** of the motor.

5.3.6.2 Cable Type

ESP cables are manufactured in a wide variety of types, i.e., with different insulating and conductor materials, constructions, and armors. The proper choice primarily depends on well conditions, most importantly on well **temperature**, and the composition, gas content, and corrosiveness of the well fluid. The main considerations [11,12] on the proper selection of the individual parts of the cable can be summed up as follows:

- The material of choice for cable conductors is **copper**, especially in deeper wells because aluminum has a lower conductivity.
- The two most common materials used for the **insulation** of the individual conductors are **polypropylene** and **EPDM** (ethylene propylene diene monomer); their temperature limits are 205 and 400°F, respectively. Polypropylene is susceptible to degradation by light hydrocarbons, CO₂, and hydrocarbon gases. EPDM materials have a much wider temperature range and are less sensitive to gases.
- **Jackets** are made from Nitril or EPDM materials, the latter being used at higher temperatures.
- **Braids** or tapes provide additional strength and protection to cable components, see Fig. 3.46.
- Metal **armor** provides mechanical protection to the cable during running and pulling and the choices are galvanized or stainless steel and Monel.

5.3.6.3 Cable Size

The main considerations for selecting the size of the power cable are (1) the physical **dimensions** and (2) the **voltage drop** along the cable. The physical size should be chosen so that the cable fits in the annulus between the casing string and the ESP unit. The voltage drop occurring in the cable is a function of the conductor size and the motor current and is a direct indicator of the energy losses occurring along the cable.

If the effect of conductor size on the operation of the whole ESP system is investigated, it is easy to see that smaller conductors mean greater energy losses and proportionally greater operational costs. However, at the same time, cable investment cost is lower than for a bigger conductor size. Bigger cable sizes, on the other hand, result in lower operating expenses but higher investment costs. Therefore, the selection of the optimum cable size should involve not only technical but **economic** considerations as well.

Before the application of optimization methods, one of the following **rules of thumb** was used to select the size of the power cable [10]:

- The cable with a voltage drop of less than 30 V per 1,000 ft of cable length was chosen. Consult Fig. E.1 in **Appendix E** where this limit is shown on the cable voltage drop diagram.
- The cable with a total voltage drop less the 5% of the motor nameplate voltage was selected.

Optimization procedures [13,14] are based on finding the least value of total operating **costs** over the expected life of the cable. The total operating cost is the sum of the **capital** and **operating** expenses and these, as described previously, vary with cable size. Because an increase of the conductor size involves increased capital costs but decreased operating costs, a cable providing the minimum of total costs can surely be found. It is easy to see that, contrary to the rules previously used, the smallest possible size may not be the best selection. Calculation of the cost items is described in the following.

The monthly payment necessary to **pay back** the capital outlay for the cable over its expected life, considering the **time value of money**, is found from the formula used for calculating partial payments of loans. In the following formula, the multiplier of the investment cost is the **capital recovery factor** that defines the variation of the capital cost's contribution to the total cost:

$$PB = CI \frac{(1+p)^N}{(1+p)^N - 1} p \quad (5.22)$$

where

PB = monthly payback for cable, \$/month

CI = capital investment for cable, \$

p = monthly interest rate, %, and

N = expected life of the cable, months.

In the formula, the monthly interest rate, p , is calculated as

$$p = \frac{P}{1,200} \quad (5.23)$$

where

p = monthly interest rate, %, and

P = prime interest rate, %/year.

These losses **decrease** the power efficiency of the system and the appropriate efficiencies for each component can be defined as detailed in the following.

6.4.2.2.1 Motor Losses

The ESP motor converts the electrical energy input at its terminals into mechanical work output at its shaft. The efficiency of the energy conversion is characterized by the **motor efficiency**, published for available motors by the manufacturer. Energy loss in the motor is determined by motor efficiency and calculated as follows:

$$\Delta P_{\text{motor}} = BHP_{\text{motor}}(1 - \eta_{\text{mot}}) \quad (6.39)$$

where

ΔP_{motor} = power loss in the motor, HP

BHP_{motor} = motor power, HP

η_{mot} = motor efficiency, —.

The electrical power required by the motor, $P_{\text{motor } e}$, is found from the motor's mechanical power and its efficiency as follows:

$$P_{\text{motor } e} = 0.746 \frac{BHP_{\text{motor}}}{\eta_{\text{mot}}} \quad (6.40)$$

where

$P_{\text{motor } e}$ = electrical power input to the motor, kW

BHP_{motor} = motor power, HP

η_{mot} = motor efficiency, —.

6.4.2.2.2 Cable Losses

As the ESP motor is connected to the power supply through a **long** power cable, there is a considerable voltage **drop** occurring across this cable. The voltage drop creates a power loss proportional to the square of the current flowing through the system, as given by Eq. (5.25) and reproduced here:

$$\Delta P_c = \frac{3 I^2 R_T}{1,000} \quad (6.41)$$

where

ΔP_c = electrical power loss in the ESP cable, kW

I = required motor current, A

R_T = resistance of the power cable at well temperature, ohms.

Electrical Submersible Pumps Manual

Design, Operations, and Maintenance

Gabor Takacs, PhD

Professor at the Petroleum Engineering Department, University of Miskolc, Hungary

Electrical submersible pumps (ESPs) are ideally suited to lift large amounts of liquids from oil wells. *Electrical Submersible Pumps Manual: Design, Operations, and Maintenance* in 2009 was the first book devoted solely to ESP technology, and this second enlarged and completely updated edition presents the latest information necessary to operate and optimize ESP systems.

Readers find a complete guide to ESP system components, system optimization, nodal analysis, and troubleshooting. This book covers the necessary mechanical, hydraulic, and electrical fundamentals. Detailed description of system components includes the latest developments such as powder metallurgy pump stages and permanent magnet electric motors. Solutions to counteract adverse well conditions (sand, gas, etc.) are fully described and the selection of ESP components is detailed. Monitoring, surveillance, and troubleshooting of ESP installations round out the coverage of this book.

Electrical Submersible Pumps Manual: Design, Operations, and Maintenance, Second Edition, makes a perfect companion for new engineers and graduate students, who need to more efficiently develop and apply their skills, or experienced engineers, who wish to further develop their knowledge based on the newest technologies presented in this book.

Key Features

- Recognize the different components of the ESP system and their operational features
- Understand how special well conditions, such as high viscosity and production of free gas or abrasives, can be overcome
- Apply the best practices to design ESP installations
- Understand the features and operational advantages of permanent magnet motors
- Prevent expensive failures by using proper monitoring, surveillance, and troubleshooting methods

About the Author

Gabor Takacs was the head of the Petroleum Engineering Department at the University of Miskolc, Hungary, from 1995 till 2012 and acting Director of the Petroleum Engineering Program at The Petroleum Institute in Abu Dhabi, UAE, from 2007 to 2010. He has more than 35 years of teaching and consulting experience in the production engineering field, authored several books on artificial lift technology, including *Electrical Submersible Pumps Manual: Design, Operations, and Maintenance* (2009) and *Sucker-Rod Pumping Handbook* (2015), both published by Elsevier.

Dr. Takacs has more than 100 technical papers to his credit. He taught various short courses in Libya, Mexico, Argentina, Indonesia, UAE, Romania, Malaysia, Peru, Oman, India, Egypt, Qatar, Kuwait, and Austria and is a well-known consultant and instructor on production engineering and artificial lift topics. In 1995–96, he was selected SPE Distinguished Lecturer, chaired the Artificial Lift TIG (Technical Interest Group) of SPE from 1997 to 2003, and received the Production and Operations Regional Award from SPE in 2017.

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