Artificial Lift

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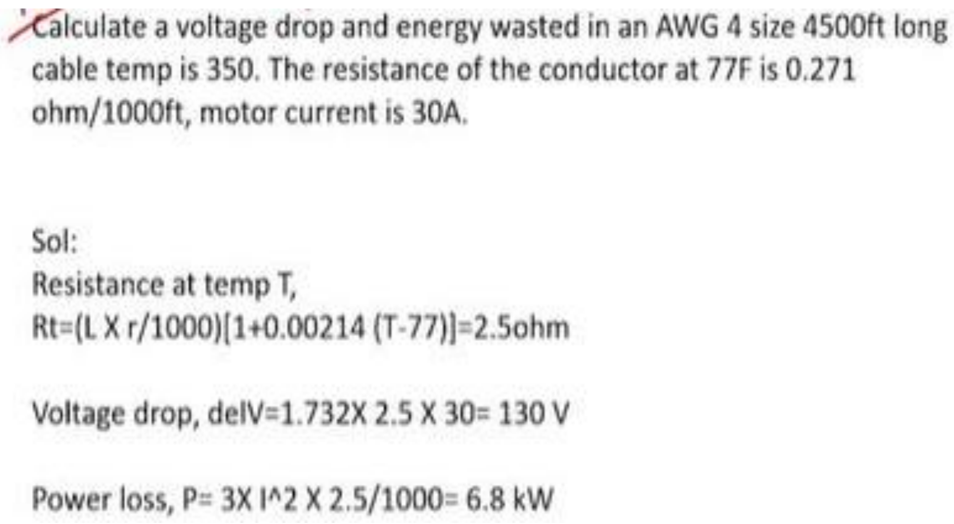
Lecture-42 ESP Basics Electrical Systems-Part-3

You know cable sizes, such as AWG 3, 4, 1, 2, 4, 6, etc. Now, let's consider a problem: Calculate the voltage drop and energy wasted in a 4500 feet long cable with AWG size at a temperature of 350 degrees Fahrenheit and a conductor resistance at 70 degrees Fahrenheit, which is given as 0.271 ohms per 1000 feet. The current is specified as 30 amperes. The solution is simple:

Total resistance (RT) can be calculated as follows:

RT = (L length × resistance per 1000 feet) × (1 + 0.00214 × (T - 77)),



Calculate a voltage drop and energy wasted in an AWG 4 size 4500ft long cable temp is 350. The resistance of the conductor at 77F is 0.271 ohm/1000ft, motor current is 30A.

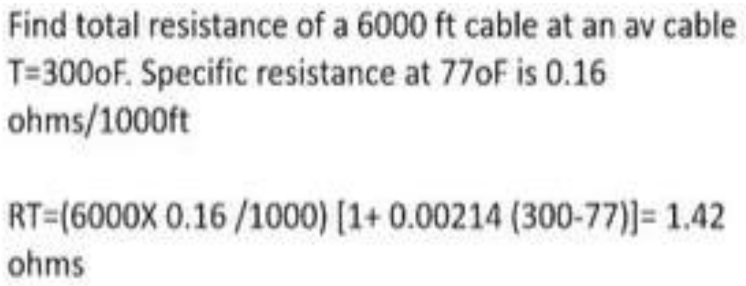
Sol:
Resistance at temp T,
Rt=(L X r/1000)[1+0.00214 (T-77)]=2.5ohm

Voltage drop, delV=1.732X 2.5 X 30= 130 V

Power loss, P= 3X I^2 X 2.5/1000= 6.8 kW

This method allows you to calculate both power loss and voltage drop. Now, let's consider another problem: Find the total resistance for a 6000 feet cable at an average cable temperature of 300 degrees Fahrenheit, with a specific resistance at 77 degrees Fahrenheit and an R value provided. The formula for RT is as follows:

If you use a longer cable, the resistance (RT) will be higher, resulting in a higher voltage drop.



Find total resistance of a 6000 ft cable at an av cable T=300oF. Specific resistance at 77oF is 0.16 ohms/1000ft

RT=(6000X 0.16 /1000) [1+ 0.00214 (300-77)]= 1.42 ohms

Regarding "Porthead MLE" or "motor lead extension," this term is used in motor lead extensions, and I found an informative picture on Baker Hughes' website that illustrates this concept. Proper insulation is crucial when connecting the motor lead extension, as any lack of insulation can allow water to enter and cause issues. In this scenario, the motor is connected to the cable. This special power cable runs from the porthead motor to the pump. You can refer to API RP 11 S4 if you seek specific specifications.

API RP 11, I believe, is intended for artificial lifting systems. Under this classification, numerous documents are available for your reference.

You can opt for a low-profile flat cable configuration when you have limited space available. However, you can use a circular cable if you have more space, especially near the motor stage. This is because the motor occupies a certain amount of space, and there remains limited space after the motor. In this case, using a flat cable is ideal, while the rest of the cable may be circular.

The cable length should be at least 6 feet longer than the upper end of the pump. This length accounts for the distance from the motor to the protector and then to the upper end of the pump. Add an extra 6 feet to this length, which will be your MLE (motor lead extension). The MLE is typically in the flat cable format and is reconnected to the porthead. The pothead should have pins to secure it in place, preventing any unintended cable movement.

Our laboratory utilizes a VFD (variable frequency drive), as illustrated in the picture below. We can adjust the speed with the VFD by changing the electrical frequency. Altering the motor speed leads to changes in the performance of the centrifugal pump. You may recall the HQ curve, which is affected by speed changes. For example, if we reduce the speed, the HQ curve looks like N1, N2, N3, and if we increase the speed, it follows a different path.

VFDs are known by various names, including adjustable frequency drive, adjustable speed drive, variable speed drive, AC drive, and many others. It's important to be familiar with these alternative names. This knowledge is essential not only for understanding various documents but also for interviews. Knowing the different names ensures you won't be caught off guard in an interview, as different terms may be used for the same device.

Typically, VFDs are employed in systems with induction motors. They are power electronics-based devices that control both frequency and voltage. By adjusting these parameters, you can change the speed of your motor.

In an ESP system with three stages, you adjust the speed of your induction motor. These motors are typically three-phase. The system consists of three stages: the rectifier stage, the inverter stage, and the control system stage.

First, you rectify the three-phase 50 Hertz frequency from 220 to 440 volts, allowing you to change the voltage. Furthermore, you can modify the output frequency (Hertz) to achieve the desired speed.

The control system regulates the output voltage, maintaining a constant voltage and frequency. In this context, Hertz refers to the frequency, which is a crucial parameter for the motor. The formula related to the number of poles and the relationship between voltage and frequency, which I previously presented, will be discussed again.

In your motor's electrical system, you'll have thrust bearings. What is a bearing? A bearing comes into play when a shaft is rotating, and within this rotating shaft, there's an impeller, motor coil, or rotor. If rotation occurs with excessive friction, it leads to significant energy loss due to the friction. Therefore, you introduce bearings to reduce this friction. Bearings are designed to prevent random movements or vibrations. There are two main types of bearings: radial bearings and thrust bearings.

Radial bearings look like this: the shaft is inside a casing, and you can observe a cross-section like this. Small balls are placed within the bearing to facilitate smooth rotation.

Think of it like a bicycle shop where they install lots of balls in the wheel hub to ensure it turns smoothly. This type of bearing is known as a ball bearing. These bearings hold radial loads, which are loads that act perpendicular to the axis.

In ESP systems, radial loads are relatively low because the system typically rotates vertically, so it doesn't exert significant extra force perpendicular to the axis. Although some load might be due to misalignment, this load is usually minimal.

We assume that there is almost no load, but we still need radial bearings. The purpose of radial bearings is to ensure smooth rotation, preventing any extra friction, resistance, or bending, even when there is a small load. Lubricating oil is needed for the bearings during rotation. If the motor already has dielectric fluid, it will serve as the lubrication for the bearing area. Lubrication is essential to reduce friction, and this type of bearing is referred to as an anti-friction bearing. With ball bearings, friction is practically negligible. Different types of bearings are available, including roller bearings, ball bearings, and journal bearings. However, we won't delve into the details here.

Next is thrust bearing. What is a thrust bearing? Imagine a motor with a stator outside and a rotor inside. Although I mentioned that there's almost no radial load, the motor contains a lot of magnets, coils, and heavy metal. Because of this metal, it exerts a downward force. To counteract this force, you need a thrust bearing. This axial load is known as a thrust load. When this load, which could be due to the weight of the motor or other factors, acts parallel to the axis on top of it, it's referred to as axial load. The entire rod or shaft will move downward if you don't hold it properly. To prevent this movement, you use a thrust bearing.

The thrust bearing is like this: you have one flat surface here and another flat surface, and the upper surface is fixed. The extra load will be applied here, transferring to this flat surface. When the shaft rotates, both flat surfaces also rotate together. You can include many balls and provide lubricating oil to minimize friction between the two surfaces. This arrangement ensures that the flat surface can handle the vertical load, while the entire axial force is transferred to the outer casing. This way, the thrust bearing only carries axial loads and not torque.

Here's how this thrust bearing works: There's a top plate connected to a shaft. The shaft looks like this, and there's a bottom plate. Another plate is sandwiched between them. So, we have the top plate connected to your casing, and the shaft has another plate between them. The shaft is rotating between these two bottom plates. This middle plate, known as the runner plate, rotates between the two bottom plates and another top plate.

So, here's the illustration: I have a shaft, which is stationary, and I have a runner plate. This is my shaft, and this is the casing or outer casing. The casing doesn't rotate or move; it has a protruded flat plate. The shaft is connected to a fixed flat plate, so when the shaft rotates, this flat plate rotates as well. This flat plate, known as the runner, rotates at high speed and transfers all the axial force to the bottom plate. It transfers the axial force, but not radial force.

Axial thrust bearings only handle axial loads, not radial forces. Radial bearings deal with radial forces, not axial forces. However, some small amounts of axial and radial forces may be accommodated, but the majority of the load is axial for thrust bearings. These bearings must be properly lubricated; otherwise, issues may arise.

This image shows the different laminations in the motor. Laminations refer to very thin sheets. These are laminations, and the shaft passes through them. This is the motor part, and it's called the outer race, while this is the inner race. The inner race is connected to the shaft, while the outer race is fixed. The shaft rotates, and the runner plate rotates along with it. The axial force is transferred to the bottom or top plate, and the bottom plate is connected to the fixed casing. The shaft and runner rotate together.

Radial and thrust bearings are present in your pump, motor, and protector section. The purpose of these isolations or restrictions is to prevent uneven forces from transferring to other parts. For example, the motor shaft goes to the pump in the motor. In between, you have an intake section and a protector section, which includes the CT (current transformer) or protector section. The protector section contains sealing and bearing arrangements because the shaft rotates continuously and enters the motor.

If the sealing and bearing fail, the entire motor will fail. For instance, if the bearings are working but the sealing fails, what will happen is that the internal motor fluid will leak outside, and outside liquid can enter. Subsurface temperatures also change because of the motor. Initially, during the installation stage, the temperature is low. When electricity is applied, the temperature rises. As the temperature increases, the entire system expands, and the liquid within the system also expands. Due to the high temperature, some of the liquid will attempt to escape from the system. After a long working life, the motor seal may become damaged. When the seal is damaged, the liquid leaks out, and the pump stops working over time. The outside fluid at a lower temperature enters, and the high-temperature fluid tries to escape. This exchange of fluids due to temperature differences can lead to wear and tear. If the system reaches a point where the fluids are fully exchanged, it can result in the system burning out. Most motor failures occur due to seal failure in submersible systems.

To address this issue, submersible pump engineers have introduced a separate seal section several feet long. The seal section includes components like bellows, an extra fluid chamber, and an isolation chamber. This section acts as a protective buffer. If the motor experiences any pressure loss due to leakage or other issues, this protective section can supply extra fluid, thus providing protection. The protector section has components like axial thrust bearings and radial bearings. These components ensure that the motor operates smoothly without taking on extra loads or challenges. The motor produces torque, while the protector acts as security and ensures that the motor is protected.

The protector section goes by various names, including motor seal, equalizer, balance chamber, and protector. These sections are placed between the intake and the electric motor. The intake section may also have a separate gas section. The motor seal section serves several purposes: pressure equalization, expansion, isolation, and absorption. It helps to equalize pressure, capture expanded fluids, isolate wellbore and motor fluids, and absorb excess pressure and fluid.

It will be absorbing extra pressure and extra load, equalizer, equalizer, equalizer will be equalizing pressure in the wellbore with the pressure outside the motor. It will provide an area for motor oil expansion and isolate wellbore fluid from the motor. It will absorb shaft thrust as well. To achieve this, it will have a mechanical seal, such as a face seal and radial seal. These seals help isolate wellbore fluid from motor fluid. Expansion bags will also be utilized. These bags expand and contract, creating a barrier. The bag material's durability depends on temperature and environmental conditions. Higher temperatures can reduce the bag's lifespan.

Labyrinths chambers will also be present to create multiple isolations or separations, ensuring that wellbore fluid remains outside. Radial bearings will restrict shaft vibrations and axial thrust loads. Thrust bearings will be included, as shown in the picture on the right side. There will be a radial bearing, o-rings, and thrust bearings. O-rings prevent outside leakage. Thrust bearings will have thrust runners and thrust blocks to handle axial loads and transfer them to the casing, which is firmly fixed with other components. Failing to use thrust and radial bearings can lead to multiple issues, as you don't want to transfer the pump load to the motor. The motor should work peacefully and safely, and seals are crucial.

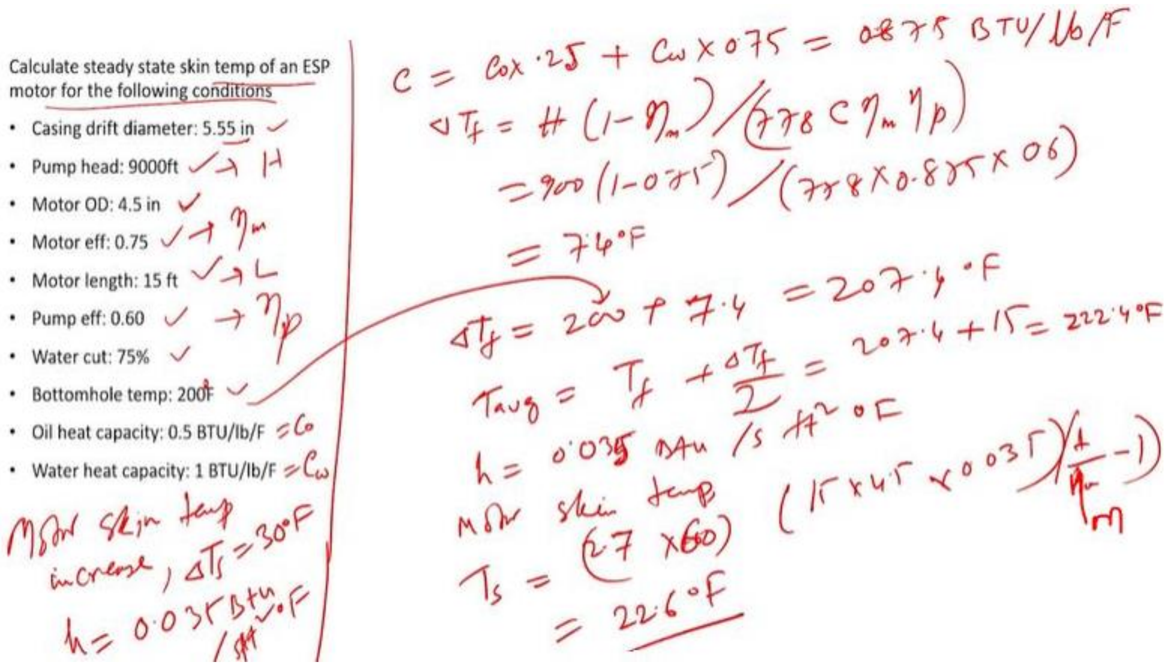
Seals prevent leakage, contain pressure, and exclude contamination. Seals serve as extra protection for the motor, along with the motor's built-in seals. In various applications, seals are also used as packing and stuffing boxes, such as sucker rod pumps and packers in wellbores. Seals are used to prevent leakage when different fluid pressures are present and rotating parts are involved. They help maintain a barrier between different fluid zones. In addition to ESP systems, seals are used in many other applications.

One potential issue is motor heat generation. When a motor runs, heat is generated due to energy conversion and losses. The conversion of energy from electrical to mechanical forms results in some energy loss, primarily converted into heat. When running a submersible motor, there will be heat generation, and calculating the amount of heat generated is essential to avoid problems. For instance, consider the following problem taken from an ESP book: calculating the steady-state skin temperature of an ESP motor based on certain conditions. The provided conditions include the casing drift diameter (5.5 inches), pump head (9000 feet), and motor outer diameter (4.5 inches).

You have only a one-inch gap, and the assumed motor efficiency is 75%. The assumed motor length is 15 feet, with a pump efficiency of 0.6. The water cut is 75%, and the bottom-hole temperature is 200 degrees Fahrenheit. The oil heat capacity is 0.5, and the water heat capacity is 1. The provided data allows you to calculate the steady-state skin temperature of an ESP.

First, you are given the oil heat capacity (C oil), water heat capacity (Cw), pump head (H), motor length (L), pump efficiency, and the heat of the pump. The combined heat capacity (C combined) can be calculated as Co multiplied by the percentage of oil (25.25%) and C water multiplied by the percentage of water (0.75), resulting in an average heat capacity of 0.875 BTU per pound per degree Fahrenheit.

Next, the surface temperature (Tf) can be calculated as H times (1 minus the motor efficiency divided by 778 times C combined times the pump efficiency). Using the provided data, this formula results in a temperature increase of 7.4 degrees Fahrenheit due to motor efficiency.



Calculate steady state skin temp of an ESP motor for the following conditions

- Casing drift diameter: 5.55 in ✓
- Pump head: 9000ft ✓ → H
- Motor OD: 4.5 in ✓
- Motor eff: 0.75 ✓ → η_m
- Motor length: 15 ft ✓ → L
- Pump eff: 0.60 ✓ → η_p
- Water cut: 75% ✓
- Bottomhole temp: 200F ✓
- Oil heat capacity: 0.5 BTU/lb/F = Co
- Water heat capacity: 1 BTU/lb/F = Cw

Motor skin temp increase, $\Delta T_s = 30°F$

$h = 0.035$ Btu/ft² °F

$C = Co \times .25 + Cw \times 0.75 = 0.875$ BTU/lb/F

$\Delta T_f = H(1-\eta_m)/(778\, C\, \eta_m \eta_p)$

$= 900(1-0.75)/(778 \times 0.875 \times 0.6)$

$= 7.4°F$

$\Delta T_f = 200 + 7.4 = 207.4°F$

$T_{avg} = T_f + \frac{\Delta T_f}{2} = 207.4 + 15 = 222.4°F$

$h = 0.035$ Btu/s ft² °F

Motor skin temp

$T_s = \frac{(15 \times 4.5 \times 0.035)\left(\frac{1}{\eta_m} - 1\right)}{(2.7 \times 60)}$

$= 22.6°F$

Now, for the motor skin temperature calculation, two assumptions are required. In this problem, the motor skin temperature increase (ΔT) is assumed to be 30 degrees Fahrenheit, and the convective heat transfer coefficient is taken as 0.035 BTU per second per square foot per degree Fahrenheit.

The average temperature (T average) is calculated as Tf plus half of ΔT, which results in 222.4 degrees Fahrenheit.

If the value of H (convective heat transfer coefficient) is not given, there is a longer process to calculate it, but it's more convenient to assume the value provided in the problem. The final formula for motor skin temperature (Ts) is as follows: Ts equals 2.7 times the motor horsepower (bhp) divided by L motor times d motor times 0.035 divided by (1 divided by ηm minus 1). This formula yields a motor skin temperature of 222.6 degrees Fahrenheit.