Artificial Lift

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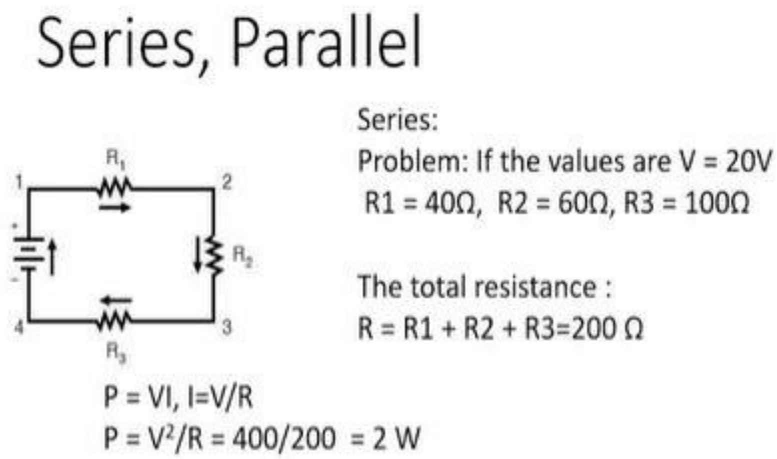
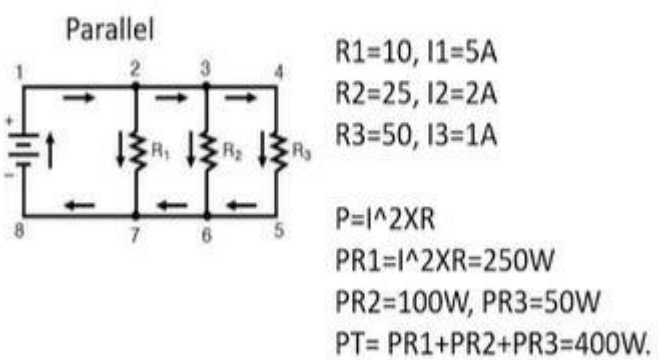
Lecture-41 ESP Basics Electrical Systems-Part-2

When you study basic electrical engineering, series and parallel connections come into play. In a series connection, you connect conductors one by one. You connect multiple conductors with all their ends simultaneously in a parallel connection, creating EMF in parallel.





For series connections with resistances R1, R2, and so on, the voltage difference (V) accumulates, making the total resistance the sum of all the individual resistances: R1 + R2 + R3 + R4 (or Rn). However, in a parallel connection, conductors run side by side, allowing different currents to flow, as some wires may have more resistance than others. This results in different numbers of electrons moving in each wire, with higher resistance wires carrying fewer electrons.

Let's delve into the math. In a series configuration, given a total resistance of 200 (R1 = 100, R2 = 100), when V equals 20 volts, you can calculate the current (I) using Ohm's law: I = V / R. With V at 20 and the total resistance (R) at 200, you obtain an amperage of 0.1 Amps. You can also calculate power (P) with the formula $P = V^2 / R$, resulting in 2 Watts.

For a parallel configuration with resistances of R1 = 10, R2 = 50, and varying current values, you'll need to calculate the power dissipated by each resistance. The power (P) in each resistance is given by $P = I^2R$, which results in P(R1) = 250, P(R2) = 100, and P(R3) = 50. Adding them together, you get a total power dissipation (P) of 400 Watts. It's as simple as that!

In an ESP system, conductors are typically connected in series, not in parallel. Series connection is the standard application, but parallel connections can be used for specific purposes.

Now, let's discuss motors. A motor is the opposite of a generator, as it converts electrical energy into mechanical energy. Due to the narrow wellbore, ESP motors are typically 5 to 8 meters long. Surface motors can vary in size, from small motors found in electronic watches to large motors used in applications such as electric trains. In submersible systems, the challenge is fitting a high-powered motor into a limited space. The casing size is usually 6, 7, or 8 inches in diameter, and the motor must fit inside the tubing, which is often only 4 to 5 inches. This limitation in diameter necessitates longer motors, ranging from 5 to 8 feet in length. In cases where very high power is needed for deep wells, the motor may be extended to lengths of up to 100 feet. To achieve this, tandem motors can be used, coupled with two motors to provide additional power. Each motor might contribute, for example, 100 units of power, so two tandem motors together can provide nearly 200 units of power. Motor torque can be calculated in pound-feet using the formula HP × (5 to 50) / N, where 5 to 50 is the conversion factor.

Let's understand how it works. Imagine you have an electrical conductor like this, with commutator brushes in place. Electric current flows through the conductor in this manner and returns here. You provide electricity; as I've mentioned earlier, the coil generates magnetic flux. When this magnetic flux intersects with the existing magnetic flux, it creates a force. If you arrange this flux system properly, combining electrically generated and magnetically generated, the magnet or coil can rotate. The electromotive force (EMF) changes as it rotates, and the magnetic poles shift gradually, resulting in continuous rotation. You can find many animation videos on platforms like YouTube for a detailed understanding of how this works.

Motors are equipped with dielectric fluid. This dielectric fluid's primary function is to prevent or limit electric discharge, effectively inhibiting sparks from occurring. The fluid acts as an insulating barrier between two electrodes, making spark formation nearly negligible. Dielectric fluids, including transformers, motors, and generators, are commonly used in high-voltage applications. These oils are typically mineral oils, paraffin-based or naphtha-based. The dielectric strength of transformer oil is defined as the maximum voltage that can be applied across the fluid without electrical breakdown. This measurement is typically expressed in kilovolts (kV).

You can see a large shaft connected to the motor in the image below, taken from Kermit Brown's book. The motor provides torque, and a coupling connects the motor shaft to the pump shaft. This coupling arrangement allows for continuous rotation and may feature a keyway or spline connection.

When you connect the shafts, the main problem that arises is alignment. If these shafts, let's call one Shaft A (the motor shaft) and the other the turbine shaft, are not in a straight line, problems can occur. Imagine one is at an angle like this, and they're trying to rotate—this is the motor shaft, and this is the turbine shaft. The turbine shaft receives torque from the motor shaft and rotates the impeller. However, if they are not in a straight line and have an angle like this, the shaft connecting to the impeller or pump will experience a lot of friction and vibration.

To create a strong joint between these two shafts might not be the solution because if there's any bend or misalignment, it can cause excessive force on the bearings and other components, potentially leading to breakages. Therefore, you need to introduce some axial flexibility to account for potential misalignment due to axial issues. Flexible coupling systems are used to achieve this flexible alignment.

With this flexibility, if one end of the shaft is here, and the other end is here, any axial movement or alignment issues will not be transferred directly. The shafts will continue to rotate smoothly. Flexible couplings allow for this flexibility, ensuring that no vibrations, additional axial loads, or misalignments are transferred from one shaft to another.

This is why tandem motors are sometimes used, as they provide slight flexibility. In this setup, one shaft can handle some misalignment without transferring uneven forces to the other shaft. The primary role of the shaft is to transfer torque, not any other forces. If any extra forces are being transferred, bearing arrangements, thrust bearings, radial bearings, or flexible couplings are used to mitigate these issues, ensuring a smooth and efficient transfer of power from the motor to the pump.

If there are any issues, such as misalignment, you should use a flexible coupling, provide additional bearings, like thrust bearings, so that only torque is transferred. Torque represents power, with rotational speed (omega) multiplied by torque giving you power. This ensures that only torque, and not any other forces, is transferred.

In ESP systems, shafts are cylindrical elements designed to only transfer torque. Unlike shafts used in marine machinery or aircraft, ESP system shafts don't transfer bending or other types of forces. When it comes to ESP shafts, only shear forces in the form of torque should be present, not tensile or compressive forces. If tensile or compressive forces exist, you need to incorporate proper mechanisms to prevent these forces from transferring between components, like from the motor to the pump.

Additional components, such as thrust bearings, can be used, and I will discuss radial bearings later. These components help ensure that only torque is transmitted, and any misalignment or other forces don't negatively impact the system.

As for the cable end and motor head, these are important parts of the ESP system. The cable delivers electricity from the surface to the motor, and the motor head acts as a protective enclosure. It is designed to insulate the motor effectively, ensuring that no water or other fluids enter the system. Designing these components carefully is crucial to avoid insulation and sparking issues.

The ESP motor consists of a rotor and a stator. The rotor is the rotating part, connected to the shaft, while the stator remains static, bolted in place. Both the rotor and stator have magnetic coils. When one coil is excited, it exerts a force on the other coil, causing the rotor to rotate continuously.

In submersible systems, a common choice is the 3-phase squirrel-cage induction motor. It's filled with dielectric fluid, which must have a dielectric strength greater than 28 kV to prevent sparks.

Typically, for 60 Hz systems in the United States, the motor runs at 3500 RPM. However, if the frequency is lower, such as 50 Hz, the motor speed drops to around 2900 RPM.

The rotor and bearing are crucial components in the motor. The rotor has conductors with gaps, while the stator has laminations. An air gap between the rotor and stator is filled with dielectric fluid to prevent sparks. If the dielectric fluid is not present, a spark could occur in the narrow, approximately 1-millimeter gap, which could damage the rotor or cause it to stop rotating. The proper dielectric fluid creates a force on the rotor laminations, driving them to rotate.

So, rotor laminations will be here. Due to these rotor laminations, a 3-phase connection will be established, comprising 1, 2, and 3 phases. This 3-phase connection provides the rotor with the force it needs from the stator, causing the rotor to rotate. For more detailed information, there are many animation videos available. I recommend watching these videos to better understand how electric motors work. Since you are studying artificial lifting systems, you'll often come across discussions about motors, rotors, and pumps, so it's essential to have a fundamental understanding of motor basics. I've provided some basics here, but you should also consider watching additional educational videos on platforms like YouTube.

The stator core comprises housing material, stator core, and stator winding. The housing material covers the entire system to prevent water or debris from entering. If heat is generated, the motor incorporates a fan to dissipate the heat. The fan is integral to the motor and enhances cooling through forced convection heat transfer. In contrast to natural convection, forced convection using a fan promotes rapid cooling.

In a submersible pumping system, space is limited, and the wellbore has no air. Therefore, a fan is not used. Instead, heat is carried away by the fluid being pumped from the wellbore. The submersible pump's stator and rotor components should be made of good conductive materials to ensure effective heat transfer. The internal transformer or motor oil should also be appropriately positioned to facilitate efficient heat conduction. Proper insulation is essential to prevent wellbore fluid from entering the system. Any heat generated must be transported to the surface; otherwise, overheating can become a significant issue.

The stator winding is typically made from polyimide or PEEK materials. Inside the stator core, copper busbars are used in the rotor. Copper is an excellent conductor, ensuring low resistance and efficient electrical performance. The force generated in the system is deliberately created and converted into torque. The formula for torque is force multiplied by radius (T = F x R).

Transformers are typically either step-up or step-down transformers. If you have very high voltage and your system requires only 220 volts, you must reduce the voltage; otherwise, the entire system could be damaged. For instance, if your system is designed for a 220-volt input and you provide an excessively high voltage, it could lead to system destruction. Therefore, voltage must be appropriately adjusted before it is supplied to the system to ensure safety and functionality.

The system works as follows: it consists of one rectangular shape component with lots of coils. On the left side, you have the primary, while on the right side, you find the secondary. The primary receives the supply voltage, and the secondary provides the voltage you need. The voltage conversion depends on the number of turns in both the primary and secondary coils and the magnetic field within. For example, if the primary voltage is 120 volts and the secondary has 100 turns, with the secondary having 1000 turns, you can calculate the output voltage. The formula is Es = (1000 / 100) * 120, resulting in an output of 1200 volts. So, in this case, you've stepped up the voltage. To reduce the voltage, you'd simply reverse the process. Typically, transformers are represented with a central core, but you often see only the circular shapes used in diagrams for simplicity.

When discussing transformers, you often talk about transformer oil, motor oil, or dielectric fluid. These fluids are tested for their dielectric strength. The testing setup usually includes a vessel with 21 beads, two of which are each 13 millimeters in size. There is a gap of around 2.5 millimeters. A potential is applied, and dielectric fluid is introduced. The dielectric fluid's quality is determined by how much voltage it can withstand during the test. Laboratories perform this simple test in a box with two electrodes, applying different voltages and measuring the results. The distance between the electrodes can be adjusted to effectively assess the dielectric fluid's quality.

Now, there is a problem to consider. A transformer converts 7200 to 480 volts using two sets of coils wrapped around an iron core. This conversion ratio is expressed as 7200 by 480. Remember this term, the transformation ratio. Transformers are rated in kVA, which stands for kilovolt-ampere, typically in the range of 11 kVA to 420 kVA for common transformers.

From the transformer, the electrical path continues to the switch box and then the venting box. First, let's discuss the junction box. A junction box is placed above the surface, typically 2 to 3 feet high. This is where the wellbore is cemented in place, and your tubing and motor are connected. The cable passes through the junction box and emerges on the other side. The cable goes to a switch box from the junction box, and sometimes it proceeds to a vent box.

The purpose of the junction box is to prevent gases, if present in the cable, from entering the switch box. The switch box contains equipment such as variable frequency drives, switches, and controls. The junction box serves as a barrier to prevent any gas-related fire hazards or sparking. The junction box receives electricity from the switch box.

The electricity goes to the transformer from the switch box, which then transfers the power to the switch box. The junction box, on the other hand, sends electricity directly to the motor. This setup ensures the safety and accessibility of the entire surface system. Typically, there's a 50-foot distance from the wellhead to the switch box and a 15-foot separation between the wellhead and the junction box. These distances are maintained for safety reasons.

The switch box contains various equipment, including a Variable Frequency Drive (VFD) system, overload and underload protection, and controller equipment. It essentially serves as the control center for the system. If you need to adjust the speed of the turbine pump, you would interact with the controls in the switch box, not the junction box.

For automation, control is primarily handled through the switch box. Switch boxes are available with different voltage ranges, typically from 440 to 4900 volts; some can even go up to 5000 volts. Additionally, they are equipped with a Variable Frequency Drive (VFD), which can change the electrical frequency. Adjusting the frequency from 60 Hertz to 50 Hertz will alter the motor speed, which, in turn, affects the pump speed. This change in pump speed impacts the entire fluid column, the development of the hydrostatic head, and the energy transferred to the fluid.

Now, regarding the cable, the cable size is such that the voltage drop should not exceed 30 volts per 1000 feet or fall below 15% of the motor nameplate voltage. Keeping voltage drop within these limits is essential. To mitigate voltage drop, you can use a variety of strategies. This might include utilizing copper conductors, possibly multiple strands, and adjusting the type of cable based on the available space, whether flat or round.

When it comes to the total cable length, it should be 100 feet more than the measured pumping setting depth. This extra length accounts for the surface connections, such as the wellbore, junction box, and switch box. Additionally, a venting system or vent box should release any gases emanating from the wellbore.

For cable materials, both copper and aluminum can be used for ESP cabling operations, though copper is the more common choice. American Wire Gauge (AWG) is typically used for measuring cables in ESP systems, ranging from 1 to 4 AWG. These may include single-strand or two-strand cables.

Cable insulation should adhere to API standards, ensuring that electrons are contained within the cable for safety. Cables typically have initial insulation, followed by a jacket, and mechanical armor (usually made of metal) covering the softer inner materials. This armor is designed to prevent wear and tear.

Common voltage ratings for submersible pump cables are 3, 4, and 4 kV. Different types of cables are available, including circular and flat cables. Circular cables can be single-strand or multiple-strand (stranded). In stranded cables, individual strands are twisted together with small gaps between them, which can trap gases. Single-strand cables are more rigid, while multiple-strand cables offer increased flexibility.