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THE PROCESS CONTROLLER's GUIDE TO

ELECTRICITY AND ELECTRIC MOTORS

This is number 5 in the Process Controller Guide series of documents

Number 1	Pollution Control.
Number 2	Water Sources and Water Treatment.
Number 3	Wastewater Treatment
Number 4	Phosphorus Removal from Wastewater.
Number 5	**Electricity and Electric Motors.**

This guide is intended to give Process Controllers an overview of electricity and electric motors to give them a better understanding of these matters.

It is intended that this document be a useful reference and training manual guide to all persons involved in the Water and Wastewater Industry.

These documents are dedicated to the thousands of men and women (both present and past) who are involved in the life critical profession of Water and Wastewater Treatment.

NOTE:

This guide is NOT intended to be a comprehensive manual on electricity and electric motors as many details have not been included and certain points have been simplified for the intended users of this guide.

Credits: some information was obtained via Google. Where original authors could be determined, this is indicated.

July 2020

THE PROCESS CONTROLLER's GUIDE TO

ELECTRICITY and ELECTRIC MOTORS

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ELECTRICITY and ELECTRIC MOTORS

PART 1.

THE BASICS OF ELECTRICITY

1.1 INTRODUCTION.

Electricity may be thought of as the presence and flow of electric charge. An electric charge is a property of matter. In the same way, mass, volume or density is a property of matter – this means that we can measure the mass of something and the volume that it occupies. One can also measure how much charge it has.

What is important is that electric charge comes in two forms: **positive (+) or negative (-)**.

Where do these charges come from? Here one needs to look at the basic building blocks of all matter – namely atoms. All atoms consist of **Protons** with a positive charge and **Electrons** with a negative charge. All atoms, except for hydrogen, also have neutrons that do not have any charge. The protons and the neutrons sit together in the centre of the atom in what is called the nucleus. This is just like our sun. The electrons move around the nucleus in orbits – just like the planets move around the sun.

Later it will be seen that there are two types of electricity: Static and Current electricity.

Electricity cannot be seen, but its effects and impacts can. *Where possible, the similarity between electricity and water will be shown to try to make the concept of an invisible thing easier to understand.*

1.2 INVISIBLE FIELDS AND FORCES.

A **field** is a property that cannot be seen as it does not have a physical appearance, but the effect that they have is very real. Some of the fields that impact on the water and wastewater industry are covered below.

1.2.1 GRAVITY FIELD.

The most commonly known field would be that of gravity. We know that if we drop something it falls down. This is due to gravity. The earth has a gravity field that points towards the centre of the earth. This means that anything falling will move in the direction towards the centre of the earth.

The effects of gravity may be may be seen the water and wastewater industry. When water flows out of a reservoir into the reticulation system - this is due to gravity. When activated sludge settles in the secondary sedimentation tank – this is due to gravity.

1.2.2 MAGNETIC FIELD.

The earth is a giant magnet that has a magnetic field with the North Pole near the top of the earth and the South Pole near the bottom of the earth. This is of use to use when we use a magnetic compass to tell us where north is. Some materials are naturally magnetic while others can be made magnetic. Exactly what causes a magnetic field is not covered in the guide.

With magnets, a north pole would repel another north pole. This means that if one moves one magnet towards another, the North Pole would try to push the other North Pole away. The north pole of one magnet would be attracted to the south pole of another magnet. This is seen in figure 1.

This is called the magnetic force. The strength of the force would depend on how strong the magnet is and their distance apart.

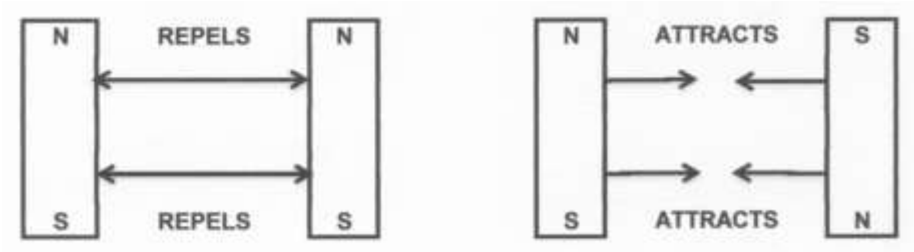

Figure 1 – INTERACTION OF TWO MAGNETS.

1.2.3 <u>ELECTROSTATIC FORCE</u>.

Electrostatic force is a force that operates between charges. Charges of the same type repel each other, while charges of opposite types are attracted together. This is shown in figure 2.

Figure 2 – INTERACTION OF LIKE AND UNLIKE CHARGES.

In this respect, the electrostatic charge is similar to the magnetic force. The amount of force acting on two charges depends on how far they are from each other. The closer two charges get, the greater the force (either pulling together, or pushing away) becomes.

Thanks to electrostatic force, electrons will push away other electrons and be attracted to protons. This force is part of the "glue" that holds atoms together, but it's also the tool we need to make electrons (and charges) flow!

Electrons in atoms can act as the charge carrier, because every electron carries a negative charge. If one can free an electron from an atom and force it to move, then one can create electricity. Atoms vary in their ability to release electrons. To get the best possible electron flow, one needs to use those atoms that release their outermost electrons easily. The measure how tightly bound an electron is to an atom is called the conductivity.

In water and wastewater treatment, the Electrical Conductivity can be measured to determine how easily the water or wastewater conducts electricity due to the presence of dissolved substances. From the Electrical Conductivity, one can estimate the Total Dissolved Solids of the water or wastewater. In a similar way one can measure the conductivity of a material.

Those elements with a high ability to conduct electricity are called **conductors**. These are the types of materials that are used to make wires and other components which aid in electron flow. Metals like copper, silver, and gold are usually used for their good conductivity properties.

Elements with low conductivity are called **insulators**. Insulators serve a very important purpose: they prevent the flow of electrons. Popular insulators include glass, rubber, plastic, and air.

There are materials known as semi-conductors that can conduct electricity under certain conditions. These are used in electronics such as cell phones, computer etc. These will not be covered here.

If there is enough electrostatic force on the outermost electron - either pushing it with another negative charge or attracting it with a positive charge – it will eject the electron from orbit around the atom and so creating a free electron.

In a copper wire that is filled with many copper atoms, there are many free electrons floating in the spaces between atoms. It is being pulled and pushed by surrounding charges in that space. In this chaos, the free electron eventually finds a new atom to latch on to. In doing so, the negative charge of that electron ejects another electron from the atom. Now a new electron is drifting through free space looking to do the same thing. This chain effect can continue on and on to create a flow of electrons called an **electric current**.

In the above: think of the conductor as a water pipe and the electrons moving along the conductor as water flowing inside the pipe. Just as water needs pressure to move along the pipe; the electrons need "pressure" to move along the conductor.

1.3 POTENTIAL ENERGY.

Potential energy is defined as mechanical energy, stored energy, or energy caused by its position. This is a property of matter that is often difficult to understand. The most important point to note is that energy cannot be destroyed – it can be changed from one form into another.

Some examples of potential energy will be given below:

1.3.1 Potential Energy in a Wound up Spring.

In order to wind up a spring (for example in a clock); one is required to turn the key. This requires one to use energy to turn the key. As one continues to use energy to keep on turning the key, the energy is being stored in the spring. As the spring unwinds the stored energy is being changed to mechanical energy to turn the hands on the clock.

The steps are:

Mechanical energy (turning the key)	➔	potential energy (stored in the spring)	➔	mechanical energy (turning the hands)

1.3.2 Potential Energy in Water at a Higher Level.

Water falling from a higher to a lower level can do work. This is illustrated in the figure 3 below of a water wheel. It can be seen that the water moves from the top where it has a higher potential energy to the bottom where it has lower potential energy. As energy cannot be destroyed; the reduction in potential energy has been transferred to the water wheel which turns. This in turn can do work.

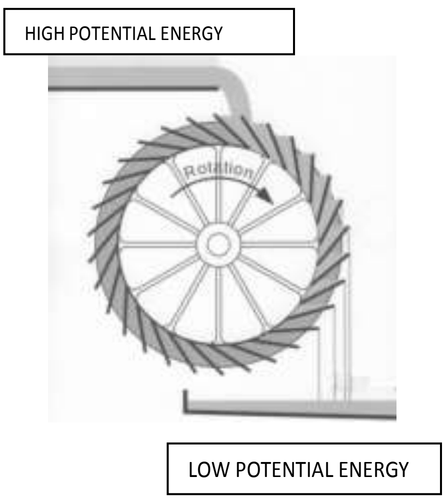

Figure 3 – SHOWING HOW POTENTIAL ENERGY CAN DO WORK.

1.3.3 Potential Energy in a pumped storage water scheme.

Here energy is used to pump water from a lower dam to a higher dam. This raises the potential energy of that mass of water. This is usually done when these is spare electricity available. When one needs to generate extra electricity, then the water is allowed to run downhill to the lower dam through a turbine. This turbine drives a generator that makes electricity that can be supplied to the town.

The steps are:

electrical energy ➔ mechanical energy ➔ potential energy ➔ mechanical energy ➔ electrical energy

1.3.3 The Conservation of Energy.

From the above examples, one can see that the energy is being transformed in the various steps. There will be energy losses such as heat from friction in bearings etc. As a result, none of the conversion steps are 100% efficient.

Having now seen what potential energy is and how the conversion of energy from one form to another takes place; one can see how this fits into the story of electricity.

1.4 TYPES OF ELECTRICITY.

As mentioned in the introduction; there are two types of electricity –Static Electricity and Current Electricity.

1.4.1 Static Electricity.

Static electricity occurs when there is a build-up of opposite charges on objects separated by an insulator. Static (as in "at rest") electricity exists until the two groups of opposite charges can find a path between each other to balance the system out.

When the charges do find a means of equalizing, a **static discharge** occurs. The attraction of the charges becomes so great that they can flow through even the best of insulators (air, glass, plastic, rubber, etc.). Charges equalizing through an air gap can result in a visible shock as the traveling electrons collide with electrons in the air, which become excited and release energy in the form of light.

The best known form of a static discharge is lightning. In a simplified explanation, this happens as described below.

This begins as static charges in a rain cloud. Winds inside the cloud are very turbulent. Water droplets in the bottom part of the cloud are caught in the updrafts and lifted to great heights where the much colder atmosphere freezes them. Meanwhile, downdrafts in the cloud push ice and hail down from the top of the cloud. Where the ice going down meets the water coming up, electrons are stripped off. This results in a cloud with a negatively charged bottom and a positively charged top. These electrical fields become incredibly strong, with the atmosphere acting as an insulator between them in the cloud.

As the storm moves over the ground, the strong negative charge in the bottom of the cloud attracts positive charges in the ground. These positive charges move up into the tallest objects like trees, telephone poles, and houses. A "stepped leader" of negative charge descends from the cloud seeking out a path toward the ground. This phase of a lightning strike is too rapid for human eyes to see.

As the negative charge gets close to the ground, a positive charge, called a streamer, reaches up to meet the negative charge. The channels connect and we see the lightning stroke. We may see several strokes using the same path, giving the lightning bolt a flickering appearance, before the electrical discharge is complete.

Another form of static electricity that can be encountered occurs when one touches a metal doorknob after shuffling your rubber-soled feet across the carpet and feels a shock. The rubber-soled shoes have picked up stray electrons from the carpet. Those electrons have built up on the shoes giving them a static charge. Static charges are always "looking" for the first opportunity to "escape," or discharge. Your contact with a metal doorknob - or car handle or anything that conducts electricity - presents that opportunity and the excess electrons jump at the chance.

1.4.2 Current Electricity.

Current electricity is the form of electricity that we are most familiar with. It makes lights work, electric motors turn etc.

It was seen above that in static electricity the charges gather and remain at rest until they grow too large and then a **Static Discharge** takes place. In current electricity, the charges are able to **constantly flow**.

In order to flow, current electricity requires a circuit. This is a closed, never-ending loop of conductive material. A circuit could be as simple as a conductive wire connected end-to-end, but useful circuits usually contain a mix of wire and other components which control the flow of electricity. The only rule when it comes to making circuits is they can't have any insulating gaps in them. If a circuit is broken, the charges can't flow through the conductor. This prevents any of the charges toward the middle from going anywhere. This is what, for example, a light switch does. When the circuit is broken then the light goes off or the electric motor stops. In the case of electric motors, this switch is called a “circuit breaker”. This is precisely what it does –it breaks the circuit. Examples of miniature circuit breakers (MCB’s) are shown in figure 4. These will be covered in greater details in the sections on Electric Motors.

Figure 4 – EXAMPLES OF MINIATURE CIRCUIT BREAKERS

If you have a wire full of copper atoms and want to induce a flow of electrons through it, *all* free electrons need somewhere to flow in the same general direction. Copper is a great conductor, perfect for making charges flow. If a circuit of copper wire is broken, the charges can't flow through the air, which will also prevent any of the charges toward the middle from going anywhere.

1.5 HOW TO MAKE ELECTRICITY FLOW.

To make water or wastewater flow uphill in pipe, one needs to apply pressure at the lower point so that the water can reach the higher point. To do this one must input energy into the system to make the water move uphill. Here the input energy from a machine and a pump increases the potential energy of the water as it rises up the pipe.

For electricity to flow, there has to be something to push the electrons along. This is called an **electromotive force (EMF)**. Part 2 will indicate how this electromotive force, that makes a current of electrons flow, is produced. An electromotive force is better known as a **voltage and is measured in volts.** The symbol is V.

PART 2.

THE PRODUCTION OF ELECTRICITY.

2.1 METHODS OF PRODUCINGCURRENT ELECTRICITY.

There are basically three methods by which electricity can be created:

1. by a chemical reaction;

2. by converting mechanical energy into electrical energy;

3. by using the light energy of the sun on photo-voltaic cells.

2.2 TYPES OF CURRENT ELECTRICITY.

There are two types of current electricity:

1. Direct Current usually referred to as DC. This is where the electrons flow in the same direction;

2. Alternating Current usually referred to as AC. This is where the electrons flow in one direction then flows in the opposite direction.

2.3 DIRECT CURRENT.

This is fairly easy to understand as the electrons are flowing in one direction and so can do work. This may be likened to someone pushing a car. By pushing the same direction, the car moves in the direction of pushing. Here the voltage stays constant and so would the electric current.

2.4 ALTERNATING CURRENT.

2.4.1 Introduction.

The concept of an alternating current is a bit more difficult to understand.

This effect can be shown in the example of a car’s engine. Here the pistons go up and down, but the crankshaft keeps turning in the same direction and causes the car to move in one direction.

Here the voltage is constantly changing – start from zero, it increases to a maximum value, then decreases through zero to a minimum value then back to zero. This is called one **cycle.**

The usual shape of the value vs time graph is the sine wave as shown below in figure 5. This shows one cycle. The vertical axis represents the voltage.

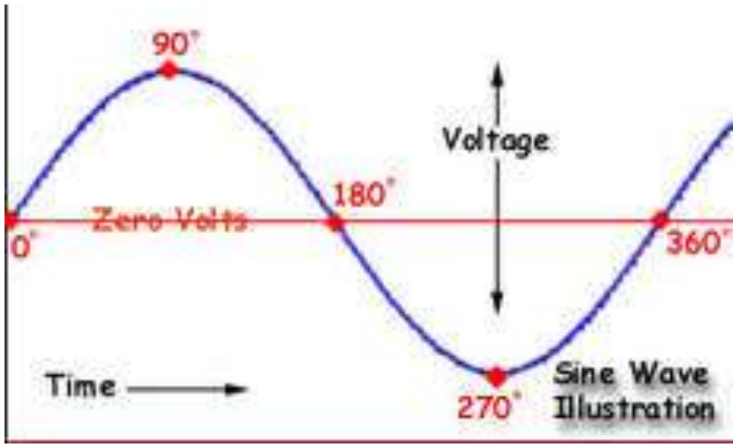

FIGURE 5 –THE VARIATION OF VOLTAGE WITH TIME IN A TYPICAL ALTERNATING CURRENT.

The frequency is the number of cycles per second. It is measured in Hertz (Hz). In South Africa, electricity is supplied with a frequency of 50 Hz. In the United States of America, the electricity supply is 60Hz.

As may be seen in the figure above, the voltage varies from a maximum positive value to a maximum negative value. From this, a question arises – What is the effective value? In other words what constant voltage would produce the same effect as this varying voltage? This EQUIVALENT voltage is known as the Root Mean Squared (RMS) value. In South Africa, the standard domestic voltage is 230 volts. This means that the RMS voltage is 230 and this is the value that you will find on most appliances. Some might say 220/250 volts. This means that you could use that appliance where the voltage in anywhere between those two values. What is important to note is that at the higher voltage, the heating effect will be higher. This will be covered in a later section.

ALL VOLTAGES REFERRED TO IN THIS GUIDE AND STATED ON APPLIANCES, HOT WATER CYLINDERS AND ELECTRIC MOTORS ETC. ARE THE RMS VALUE.

With the RMS value being 230 volts; the peak value is 230/0.707 = 325 volts maximum value and **-**325 volts minimum value. The factor of 0.707 is calculated mathematically but this will not be done here.

Figure 5 shows how the voltage varies during one cycle. The electrical current will vary in the same pattern. It may be seen then that at two points in a cycle, both the voltage and the current are zero. That means that at that instant no work is being done. When one switches on an electric light, the light seems to have the same brightness at all times. In fact, the brightness is continuously varying. But because this is happening many times per second, one does not notice this. The element in a kettle or a hot water cylinder will have the same variation in heat output. This again would not be noticeable.

2.4.2 Single Phase Supply.

For normal domestic use, this variation in light or heating in an oven or a hot water cylinder is not noticeable. The domestic power supply normally has 3 wires - these are LIVE (Blue colour); Neutral (Brown colour) and Earth (Yellow and Green colour). IT IS VERY IMPORTANT THAT WHEN ELECTRICAL CONNECTIONS ARE MADE, THAT THE VARIOUS WIRES ARE **NOT** MIXED UP. The reason for this will be explained later. Some electrical appliances are “Double Insulated” – shown by a square within a square - so they don’t need and earth connection.

The above described electricity supply with **one** live wire is called a **Single Phase supply.**

2.4.2 Three Phase Supply.

It was seen above that at certain times in the cycle, the voltage is zero. It was further indicated that in respect of lights and other small powers usage this was not a problem. However, in industrial use, especially in electric motors this ongoing variation in power output would be a problem. This is covered later in the part covering electric motors. Therefore a different system of electricity supply is required where the power output is constant.

Instead of having just one distinct power variation; one could have three cycles running continuously but with a 120 degree delay with the second and 240 degree with the third. This is shown in figure 6 below. As there are three cycles, this is known as **Three Phase Electricity**.

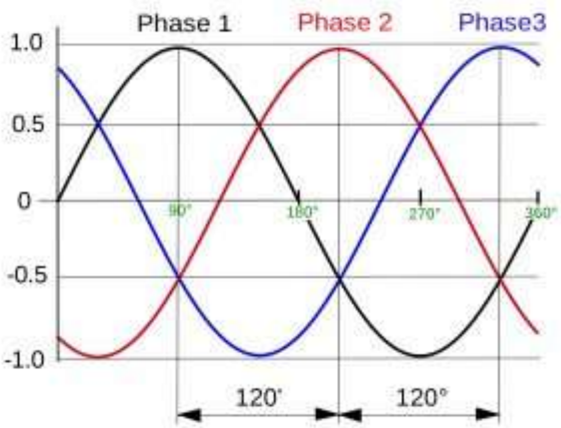

FIGURE 6 – A THREE PHASE ELECTRICITY SUPPLY.

The differences between three phase electricity supply and single phase supply will be covered in greater detail later.

2.5 ELECTRICITY PRODUCED BY A CHEMICAL REACTION.

There are chemical reactions that make the electrons move along a conductor is to provide a difference in energy between one end of the conductor and the other end.

Two types will be mentioned here:

1. the common dry-cell battery;

2. fuel cells.

2.5.1 The Dry-cell Battery.

One example is the Zinc-Carbon Battery. Here the chemical reaction is:

$$Zn \rightarrow Zn^{2+} + 2e^{-}$$

$$2Mn^{4+} + 2e^{-} \rightarrow 2Mn^{2+}$$

The Zinc (Zn) casing supplies the electrons that the Manganese (Mn) in the body of the battery takes up. When either ingredient is used up, then the battery will no longer produce electricity. This type of battery produces 1.5 volts. The Positive terminal inside the battery is made of carbon, while the zinc casing acts as the negative terminal.

Below is shown a typical electrical circuit with a battery as the power source and a lamp as the load. The direction of flow of the electrons may be seen in figure 5. ***Traditionally, one was taught that the flow of electricity was from Positive to Negative – this is actually incorrect.***

In a symbol of a battery; the longer line is always the positive terminal and the shorter line is the negative terminal.

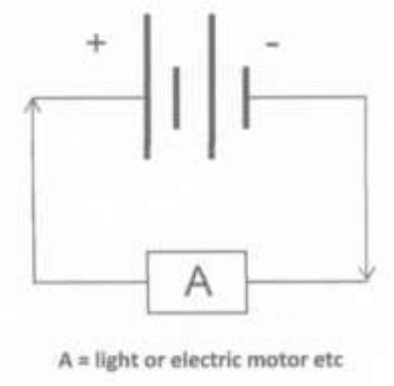

Figure 5 – A SIMPLE ELECTRICAL CIRCUIT WITH BATTERY AND A LIGHT BULB.

The above type of battery is called a dry-cell battery, because it does not contain any liquid. Another similar size battery is the Manganese Alkaline battery that also uses a chemical reaction. There are specialist batteries such as Silver Oxide that are used in hearing aids etc.

2.5.2 Fuel Cells.

If an electric current is passed through water it will be broken up into hydrogen and oxygen. This is caused electrolysis. It is possible to “turn” this reaction around, so that hydrogen and oxygen are allowed to combine in a special way to create an electric current. This is what a fuel cell does.

Fuel cells are different from most batteries in requiring a continuous source of fuel and oxygen (usually from air) to keep the chemical reaction running and so produce electricity. In contrast, in a battery the chemical energy usually comes from metals and their ions or oxides that are commonly already present in the battery as seen above. An example of a hydrogen fuel cell is shown below in figure 6:

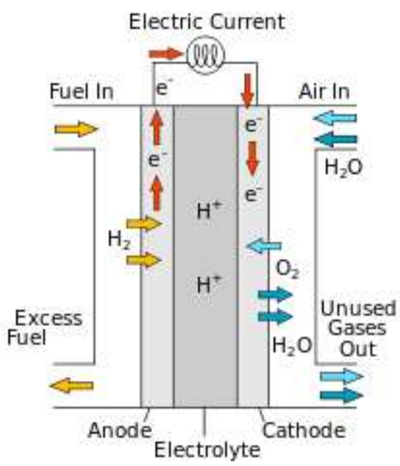

Figure 6 – LAYOUT OF A TYPICAL HYDROGEN FUEL CELL.

The by-product of the hydrogen fuel cell is water. A single hydrogen fuel cell produces about 0.7 volts, so many have to be stacked together to get a useful voltage. Other chemicals can also be used. These will consist of an oxidizing agent and a reducing agent.

2.6 ELECTRICITYPRODUCED BY CONVERTING MECHANICAL ENERGY.

First it is necessary to note the impact of magnetic fields and of conductors moving in a magnetic field.

In section 1.2.2, mention was made of magnets and magnetic fields. Now one looks at what happens when a wire or some other conductor is moved through a magnetic field. This would require the input of some energy to move that wire or other conductor. This movement of the conductor through the magnetic field forces the flow of electrons and this creates electricity.

In figure 7, the black object is the conductor that is moved between the north and south poles of the magnet. This will require mechanical energy to do this. The electricity that is produced flows out through on the wires attached to conductor, through the circuit and back through the other wire into the conductor – thus completing the circuit. The circuit must not have any breaks in it or the electricity will not flow.

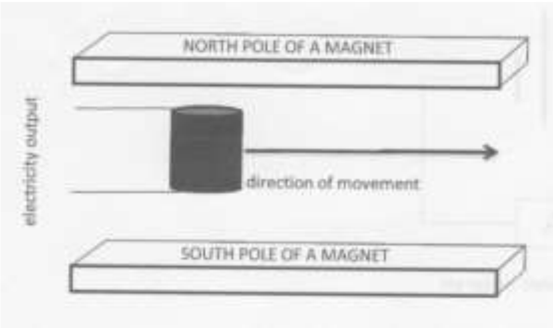

Figure 7 – A CONDUCTOR MOVING IN A MAGNETIC FIELD.

In the above example, when the conductor reached the end of the magnets, then the generation of electricity would stop. This would not be very useful. One needs find a way of making the generation of electricity (by moving the conductor through a magnetic field) a continuous process.

This would be possible if the conductor was surrounded by a magnetic field and the conductor rotated. This may be seen in a simplified form in figure 8.

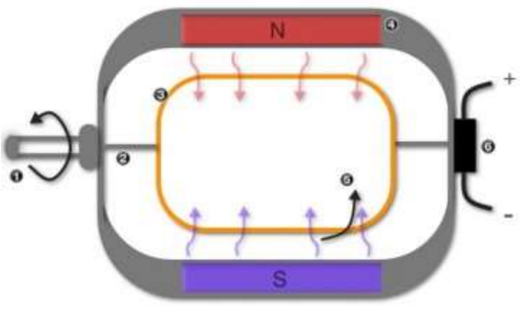

Figure8 – A SIMPLIFIED LAYOUT OF A CONDUCTOR ROTATING IN A MAGNETIC FIELD.

One should think of an electricity generating machine as an 'energy engine' that **converts mechanical energy into electricity.**

All electricity generating machines consist of two basic parts (as seen in figure 8); a fixed part called the **stator** and a moving part called the rotor (also known as the armature).

There are two types of electrical generating machines:

1. where the magnetic field in comes from the stator and the conductor is the rotor. This is traditionally called a “Generator”. This type of generator can produce alternating current OR direct current;

2. where the magnetic field comes from the rotor and the conductor is the stator. This is traditionally called an “Alternator”, because it generates only alternating current. This can later be converted to direct current as in does in a motor car.

2.6.1 <u>The Electrical Generator where the Magnetic Field comes from the Stator.</u>

This is best explained by referring to the figure 9 below.

LETTER(S) IN FIGURE	**WHAT IT REPRESENTS**
N	North pole of the Magnet
S	South pole of the magnet
J, K, L, M	Parts of the rotor
A, B	The contacts that transfer the electricity from the rotor
P, Q	The electricity output that will used

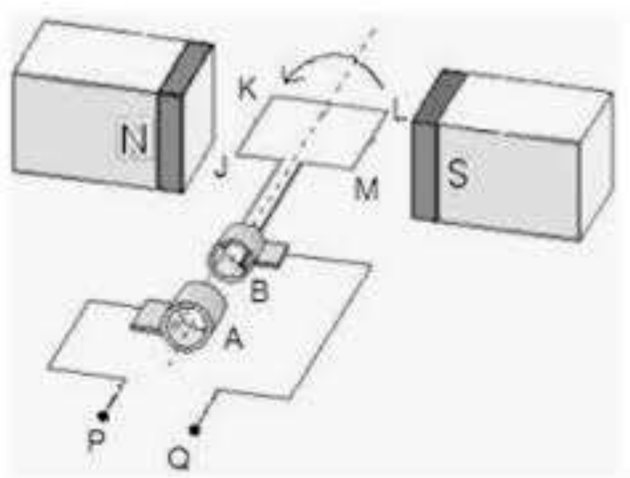

Figure 9 – BASIC PARTS OF AN ALTERNATING CURRENT GENERATOR.

Using the above figure for reference, when the part of the rotor labelled L M is at the bottom half way between the two magnets, it will not produce any electricity. As the rotor turns through 90 degrees, it passes the south pole of the stator magnet and produces the maximum voltage. A quarter of a revolution later, it has turned 180 degrees from its starting point and is again half way between the two magnets. This means that at this point it will not produce any electricity. A quarter of a revolution later, it is next to the North Pole having turned 270 degrees from its starting point. Here it will again produce the maximum voltage BUT in the other direction. A quarter of a revolution later, it will have turned 360 degrees and will be back at its starting point.

The parts of the rotor where the contact is made with the external electrical circuit (marked as A and B) are called the SLIP RINGS. This is because the BRUSHES that make the actual contact slip over the slip rings. These brushes are usually made of carbon. This is because they conduct elect electricity and usually being softer than the slip ring material (usually copper) can be replaced more easily when worn down. There is usually a spring gently holding the bushes against the slip rings.

The change from minimum voltage to maximum voltage, again to minimum voltage and then to maximum voltage in the other direction; is not sudden but changes gradually as shown in figure 5 earlier. This pattern is known as a Sine Wave because the value at each point is equal to the Sine of the angles seen in Table 1 below. Only a few values have been shown in the table.

TABLE 1 – SHOWING SINE VALUE OF ANGLE OF ROTATION.

ANGLE OF ROTATION (degrees)	**SINE OF ANGLE OF ROTATION**
0	0.00
45	0.71
90	1.00
135	0.71
180	0.00
225	-0.71
270	-1.00
315	-0.71
360 (=0)	0.00

It will be seen that these values coincide exactly with the sine wave shown in figure 5.

It was noted earlier that the frequency (number of cycles per second or Hertz – Hz) of electricity supplied in South Africa is 50Hz. Per minute, this equals 50 x 60 (seconds per minute) or 3 000 cycles per minute. It is also seen that the basic generator shown above has ONE North Pole and ONE South Pole – this is a total of TWO poles. This means that if the rotor turned at 3 000 revolutions per minute (rpm); then the alternating current would have a frequency of 50 Hz which matches the South African supply. This would mean that whatever was driving the rotor would need to rotate at 3 000 rpm unless there was a system to change the speed from the machine that was doing the driving to the generator speed.

Assuming that the main driver was running at the same speed as the generator then this would be called "Direct Drive". For a small electrical generator driven by a small petrol engine, this is not a problem. For a larger system such as that used for standby electricity generation purposes driven by a diesel engine, this is too fast for a long service life for the engine. The solution is to have TWO sets of north magnets AND TWO sets of south magnets. This means that the rotor of the generator need to rotate at 1 500 rpm only in order to produce alternating current at 50Hz. This is the most commonly speed used for standby generators. The layout of the generator would look the same as above except there would be two north poles and two south poles.

2.6.2 Using the Above Type of Generator to Produce Direct Current Electricity.

The rotor turning in the magnetic field would work exactly the same as above. In figure 5, one can see for half the time the voltage is positive and half the time it is negative. If the electricity could be "collected" only at that time when the voltage was positive, then one would have direct current BUT it would be varying in voltage all the time from 0% to 100%. The voltage output would look like that shown in figure 10. At 50Hz, there would be electricity being generated for 1/100 second, then no power for 1/100 of a second, again electricity for 1/100 of a second and so on. This means that electricity is being produced only 50% of the time – not a good system.

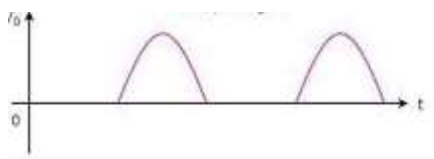

FIGURE 10 – SHOWING WHEN ELECTRICITY BEING GENERATED ONLY 50% OF THE TIME.
(voltage on vertical axis and time on horizontal axis).

It was seen in figure 9 how the electricity was been transferred from the rotor via the **SLIP RINGS** to the electrical circuit 100% of the time. Figure 11 shows how the electricity is transferred from the rotor via the **SPLIT RING COMMUTATOR** to the electrical circuit 50% of the time.

Figure 11 shows the difference between the two layouts.

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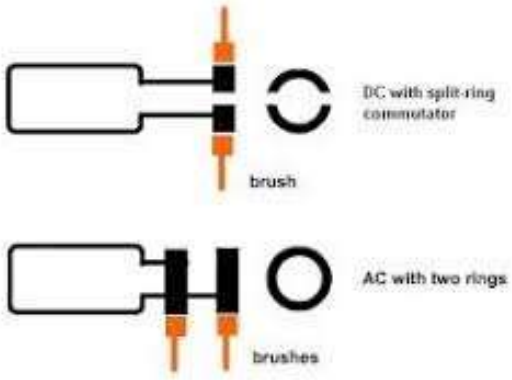

Figure11 – SHOWING THE DIFFERENCE IN THE LAYOUT BETWEEN DC AND AC ELECTRICAL COLLECTION SYSTEMS.

In figure 11, the commutator has only two segments. As indicated above, this would give a big variation in electrical output. This could be improved if the rotor or armature had many separate parts all leading to separate "collection" points on the commutator. These individual "collection" points are called the segments of the commutator. This may be seen in figure 12 below:

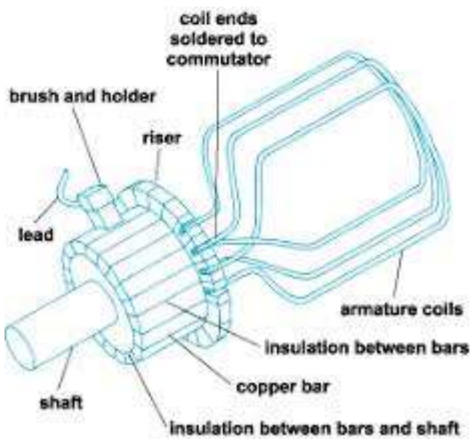

Figure 12 – SHOWING A COMMUTATOR WITH MANY SEGMENTS

This layout would give a much smoother supply of electricity.

2.6.3 <u>The Electrical Generator where the Magnetic Field comes from the Rotor.</u>

As indicated earlier the rotor possesses the magnetic field and as it rotates, it makes the electricity flow in the stator. This is shown in figure 13 below. As indicated earlier, this electrical generating system has the disadvantage of producing electricity where the voltage varies from 100% to 0% and to 100% again. As also seen earlier, one way to overcome this variation, is generate 3 phases of electricity again offset by 120 degrees. This is shown in simplified form in figure 14 below. The rotor is not shown to make the layout clearer to understand. The 3 phases are called A, B and C.

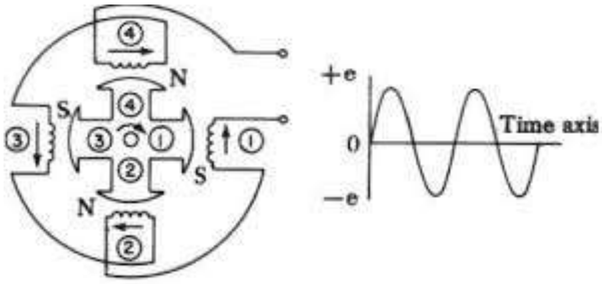

FIGURE 13 – SIMPLE DESIGN OF A SINGLE PHASE ALTERNATOR and SHOWING OUTPUT PATTERN.

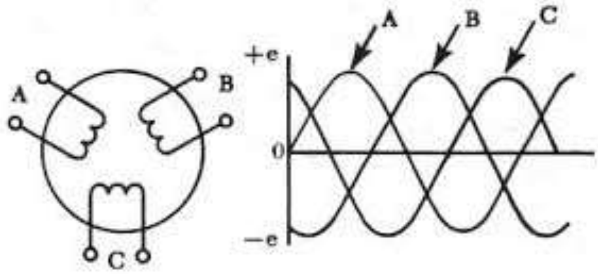

FIGURE 14 – SHOWING PARTS OF A 3 PHASE ALTERNATOR and SHOWING OUTPUT PATTERN.

2.7 SOURCES OF MECHANICAL ENERGY WITH NO INTERMEDIATE STAGE.

In section 2.6, it was shown how mechanical energy was converted into electrical energy. This section will look at various sources of mechanical energy. These include:

1. engines using a fuel as the energy source;
2. using energy of wind;
3. using potential energy of water;

2.7.1 Engines as a source of mechanical energy.

In section 2.6.1, a brief mention was made of the use of an engine to produce mechanical energy that in turn was used to drive an electrical generator.

Here two types of engines will be covered:

1. the reciprocating engine. This like the engine of car or a truck where pistons are driven downwards by the pressure of the fuel being burnt;
2. the gas turbine. This is like the engine that powers a jet plane where a turbine spins due to the pressure of the exhaust gases from the fuel being burnt.

The initial fuel source for the reciprocating engine would be petrol or diesel fuel. It is also possible to run these engines on Liquefied Petroleum Gas (LPG); Liquefied Natural Gas (LNG) or gas from an anaerobic digester at a wastewater treatment works or other industrial process.

Where a reciprocating engine is used to drive an electrical generator, the maximum electricity output is generally about 1 MW.

The gas turbine would run on Jet Fuel (similar to paraffin) or diesel. These can be much more powerful. The Eskom gas turbine units in the Western Cape and the Southern Cape generate up to 147 MW of electricity from each unit.

Both these types of engines would use a non-renewable energy source (except digester gas). This means that these fuels come from sources that will one day run out. All the various types of fuels indicated above contain a large percentage of carbon. When this carbon is burnt, it produces carbon dioxide. This is known as a “Greenhouse” gas as it contributes to global warming. This is a most undesirable effect as it will change our climate for the worse.

2.7.2 Wind Driven Turbines as a Source of Mechanical Energy.

As the name suggests, these use wind power to turns blades that drive an electrical generator. As the wind will never “run out”; these wind turbines are referred to as RENEWABLE energy sources. One of the major problems with generating electricity using wind power is

NO WIND = NO ELECTRICITY

Electricity itself cannot be stored except in very small quantities. This matter will be covered later. Wind turbines need to be very tall – from 50 to over 100 metres high. Even the big ones in areas with a strong wind can produce only about 5 megawatts each. This means many are needed to produce a reasonable amount of electricity. Some people do not like to see the so-called WIND FARMS as shown below in figure 15. There are also concerns that birds can be killed by the rotating blades. The various part of a wind turbine are shown in figure 16.

FIGURE 15–SHOWING A FAIRLY LARGE WIND FARM.

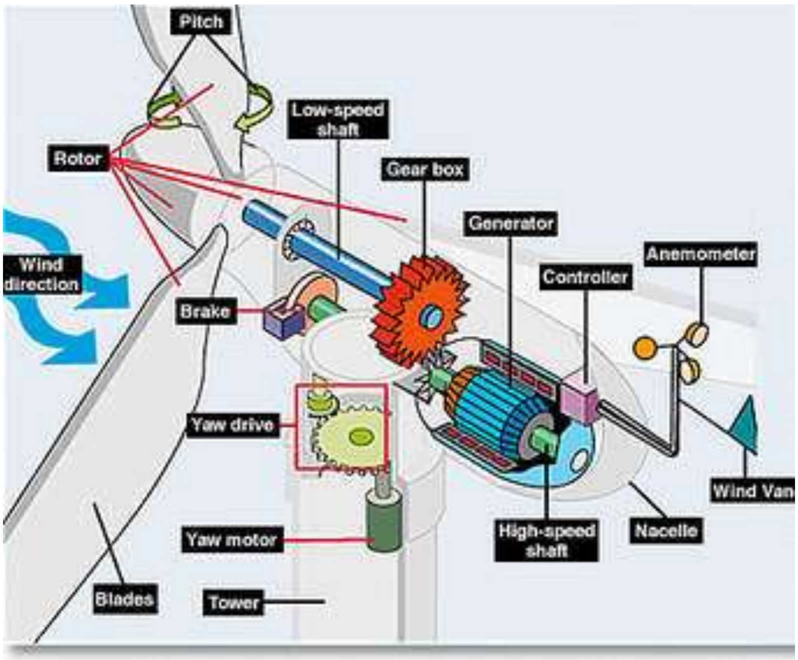

FIGURE 16–SHOWING THESE VARIOUS COMPONENTS OF A WIND TURBINE DRIVEN ELECTRICITY GENERATOR.

2.7.3 Using the Potential Energy of Water.

This is usually known as Hydro-Electric Power. A simple example was given in section 1.3.2 when the concept of Potential Energy was introduced. The water wheel as a source of power has been used for a very long time but was used to turn a shaft that in turn drove machines like mills for making flower from wheat. They were not used to generate electricity. The layout of a typical hydro-electric power generating station is shown below in figure 17.

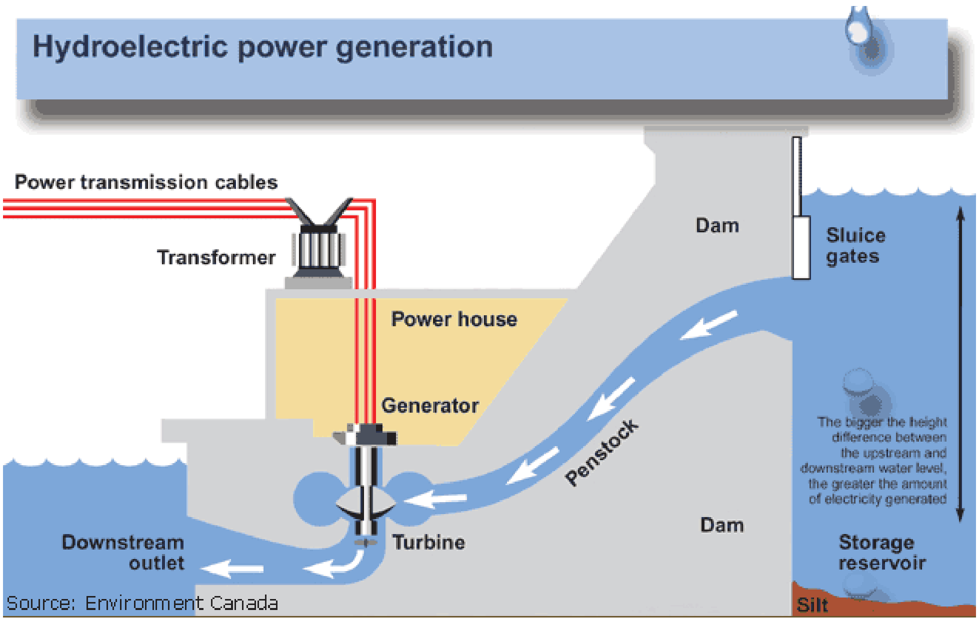

FIGURE 17 – LAYOUT OF A TYPICAL HYDRO-ELECTRIC POWER STATION.

As maybe seen in the figure above, the pressure of the water running down the feed pipe turns the turbine and this in turn turns the electrical generator and so produces electricity.

Unfortunately, with South Africa being a water scarce country, there are only a few suitable sites for hydro-electric power stations. Two of the older ones are at the Gariep Dame on the Orange River that can generate 360 MW and the van der Kloof Dam also on the Orange River that can generate 240 MW. South Africa can obtain about 1 000 MW from the Cahora Bassa hydro-electric power station in Mozambique.

2.8 SOURCES OF HEAT ENERGYTO PRODUCE ELECTRICITY.

In the 3 examples above, the rotational energy from the engine or turbine turns the electrical generator. There is no intermediate step – ignoring any speed changing device such as a gearbox.

This section will look at various sources of heat energy that is converted into mechanical energy through an intermediate stage. This intermediate stage is the production of steam. It is **THIS** steam that turns the turbine that turns the electrical generator. One can see that there are various steps in the production of electricity.

The various heat sources include:

1. using energy from a nuclear reaction;
2. using energy from combustion of solid or liquid fuels;
3. using heat energy from the sun;
4. using heat energy from the earth.

2.8.1 Using Energy from a Nuclear Reaction.

Certain elements are radio-active in that they breakdown into other elements and release heat. It is this heat that is used to generate steam. A heat exchanger is used to cool the steam after use to turn it back into water so that it can be re-heated in the reactor. This is shown in a simplified flow sheet in figure 18. The system shown uses cooling towers to condense the steam into water so it can be used again. Koeberg Nuclear Power Station in the Western Cape uses seawater instead.

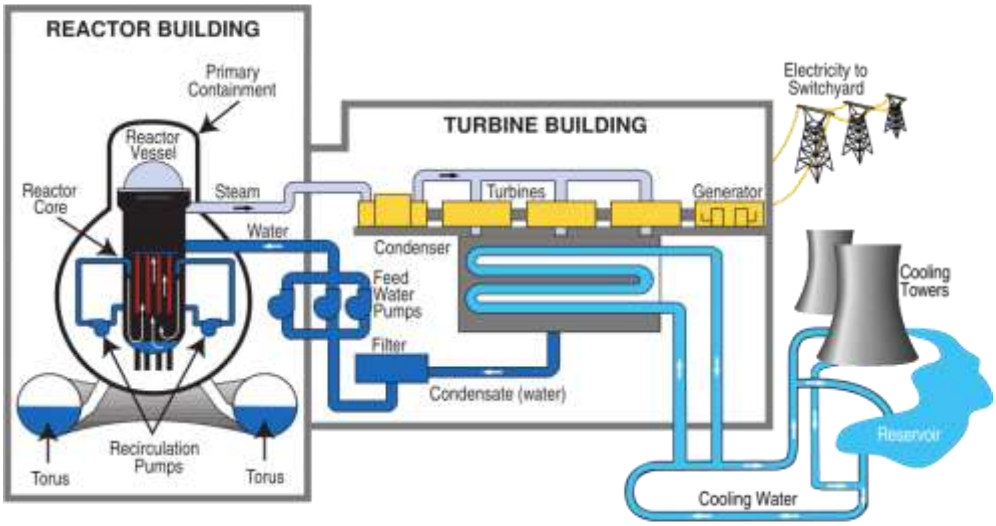

Figure 18 – FLOW SHEET OF A TYPICAL BOILING WATER REACTOR NUCLEAR POWER STATION.

The nuclear power station produces a small amount of carbon dioxide in contrast with those systems burning a carbon based fuel such as coal, gas or oil. However; it does produce a highly radio-active waste that remains dangerous for thousands of years. It must, therefore, be stored in special containers in a place especially designed for this. This is the main reason that many people protest against the use of nuclear energy for electricity generation.

2.8.2 Using Energy from Burning of a Carbon-Based Fuel.

In this case, the fuel may be a solid as coal or liquid as oil, Liquefied Natural Gas (LNG) or more rarely Liquefied Petroleum Gas. In this case, the heat source is the burning of the fuel in a boiler. A simple typical flow sheet is shown in figure 19. The cooling tower to condense the steam is NOT shown.

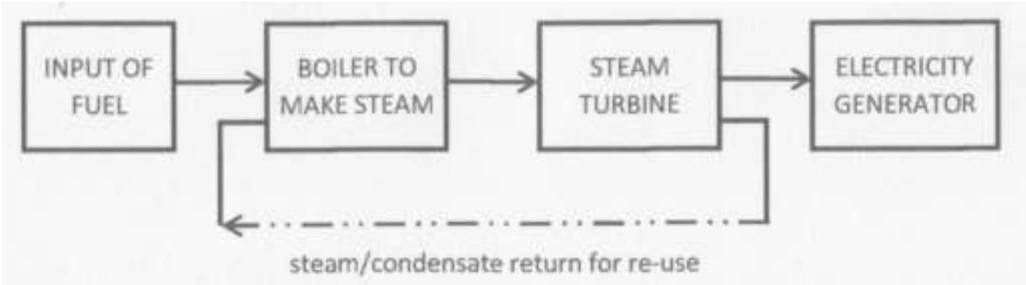

Figure 19 – FLOW SHEET OF A TYPICAL COAL FIRED POWER STATION.

2.8.3 Using Heat Energy from the Sun.

The sun is a giant nuclear reactor that produces heat and light. Because it is far away, the heat is not strong enough to do much work for us. If one concentrates the sun's rays, then it can do useful work for us. A simple example is the solar cooker as shown in figure 20:

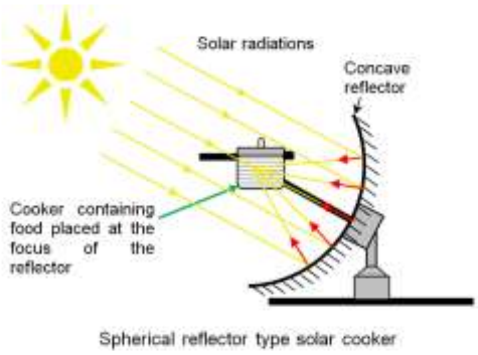

Figure 20 – A SOLAR COOKER USING THE SUN's HEAT ENERGY.

This idea can be expanded to large scale enough to make electricity as seen in the flow sheet shown in figure 21.

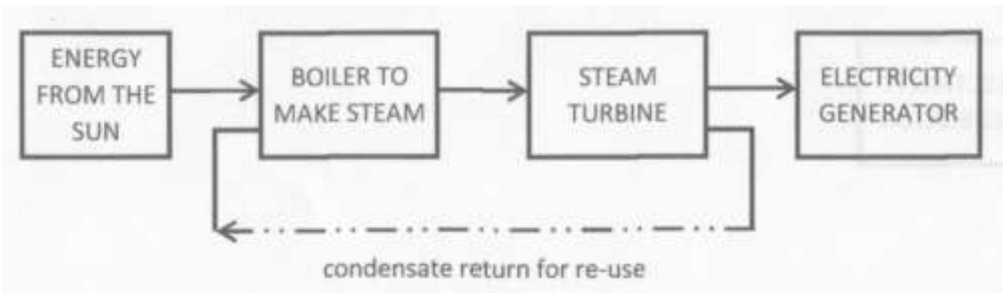

Figure 21 – FLOW SHEET USING HEAT FROM THE SUN TO PRODUCE ELECTRICITY.

How the above system works on a large scale is shown below in figure 22. This system is known as Concentrated Solar Power (CSP).Figure 22 shows what a Concentrated Solar Power layout looks like.

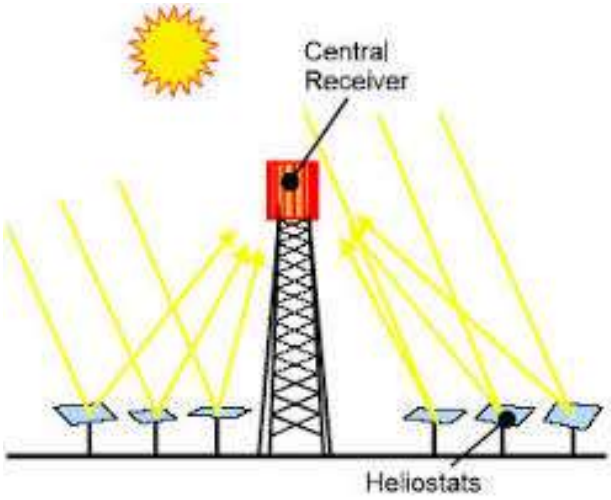

Figure 22 – HOW A CONCENTRATED SOLAR POWER SYSTEM WORKS.

By Hp.Baumeler - Own work, CC BY-SA 4.0,
https://commons.wikimedia.org/w/index.php?curid=60311252

Figure 22 – AERIAL VIEW OF A CONCENTRATED SOLAR POWER FACILITY.

As the Concentrated Solar Power relies on the sun's heat energy, it will only work when the sun is shining.

It would also have limited output in early morning and late afternoon. These facilities are only feasible in areas with little cloud cover – for example in the Northern Cape.

There is one way to overcome the problem of no heat input at night time and that is to heat salts such as sodium nitrate or potassium nitrate until they melt at over 500 degrees Celsius. The molten salts are used to make steam. During the day, the salt liquid gets hotter and hotter while during the night, the hot salt is used to make steam to drive a turbine to drive the generator and so produce electricity. The next day it gets heated again. In this way, it is possible to get 24 hours per day electricity production.

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2.8.4 Using Heat Energy from the Earth (Geo-Thermal Energy).

The earth deep beneath our feet is very hot. This is seen when volcanoes erupt and bring the hot molten rock to the surface. This is also seen at many places in South Africa where there are hot water springs. These are not hot enough to produce electricity. It is, therefore possible to drill a deep hole in the ground, pump water down to the hole to be heated and return to the surface as steam. There are a few of these plants in the world. The other way, is to find a place where the steam comes naturally to the surface. The steam is captured and used to drive a steam turbine. There are some of these plants in Iceland. The flow sheet is shown in figure 23:

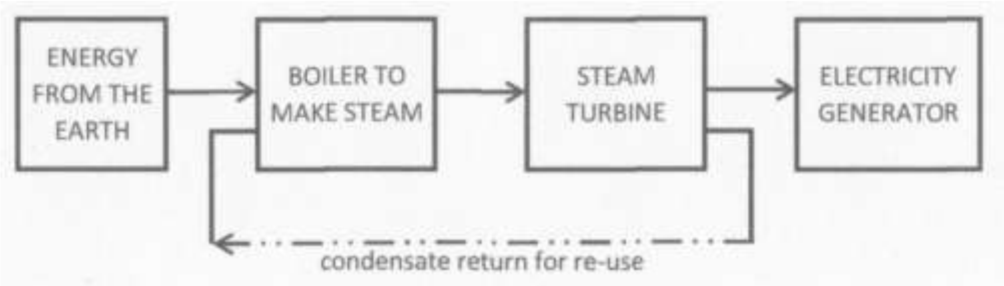

Figure 23 – FLOW SHEET OF A GEO-THERMAL POWER PLANT.

2.9 USING LIGHT ENERGY FROM THE SUN TO PRODUCE ELECTRICITY.

Section 2.8.3 showed where the heat energy from the sun to heat materials and use this heat to produce electricity. It is also possible to use the LIGHT energy from the sun to produce electricity. This is called the photo-voltaic effect,

Photovoltaic solar energy is a clean, renewable source of energy that uses solar radiation to produce **electricity**. It is based on the so-called photoelectric effect, by which certain materials are able to absorb photons (light particles) and release electrons, generating an electric current.

This system can produce only direct current. These systems can work well for small borehole pumps in remote areas, powering electric fences etc. Any unused power can be stored in batteries for use later. See the next section.

2.10 STORING OF ELECTRICAL ENERGY

The demand for electricity is not constant throughout the day. It would be useful if one could store electrical energy and make it available when required.

One can think the storage of electrical energy like that of the storage of water in a water reservoir. Water is transferred into the reservoir where it acts like a balancing tank. When the demand is low, the water is pumped into the reservoir faster than it is taken out and so the water level rises. When the demand is greater than the feed rate to the reservoir, then the water level drops.

On the other hand, electricity is much more difficult to store. Three types of storage types will be covered:

1. the storage battery,

2. water potential energy storage;

3. heat energy storage.

2.10.1 <u>The Storage Battery.</u>

It was seen in section 2.5, that are batteries that produce electricity through a chemical reaction. It was note there that when the chemical(s) are used up then the battery stops producing electricity. This is because the chemical reaction cannot be reversed. It was also noted in section 2.8.3 and 2.9 that these methods of producing electricity work only when there is sufficient sun.

There are certain types of batteries wherein the chemical reaction IS reversible. The three most common types are:

1. <u>Lead – Acid</u>. This is used in motor cars and trucks for operating the starter motor and running the lights etc. They are also the main type used to start standby generators. They are often used to store electricity produced via photo-voltaic electrical generation systems in homes and offices. Each battery cell produces 2.05 volts. A 12 volt car battery would have 6 cells;

2. <u>Nickel – Cadmium (NiCad)</u>. These are commonly used in torches, radios, TV remotes etc. Their main disadvantage is that they have a "memory effect". This means that they must be discharged fully first, before being recharged. If recharged before they have been discharged, they lose much of their storage capacity with time. Their output voltage is 2.1 volts;

3. <u>Nickel - Metal Hydride (LiMH).</u> These are similar to the above;

4. <u>Lithium Ion (Li-ion.</u> This is a more modern type of battery that is does not have a memory effect. These are used in electric cars. These batteries are more expensive but have a better power to weight ratio – means more electricity available from a given mass of battery. Each battery produces about 3.2 volts.

These batteries are charged with and produce direct current only. It is possible through an appliance known as an "Inverter" to transform direct current into alternating current. This is quite complicated, so it will not be covered here.

2.10.2 <u>Using Potential Energy of Water.</u>

Reference is again made to section 1.3.2 where the process converted the potential energy of water was converted into work. Above it was shown that when the water demand was less than the available water feed, then the level in the reservoir rose.

A similar concept may be used where water is pumped to a higher level reservoir using electricity where the availability exceeds the demand. At times when the demand exceeds the availability, then the same water may be run back down the pipe to turn a turbine that in turn produces electricity. This is just like the hydro-electric scheme covered in section 2.7.3.

In the pumping cycle, the incoming electrical energy is converted in potential energy held by the water being at a higher level. When the water runs back down the pipe, its potential energy is turned into electrical energy. Some pump storage schemes use the same turbine to pump the water back to the top reservoir.

The Eskom Palmiet River pumped storage scheme can produce 400 MW. South Africa has a total of 2 910 MW of installed pump storage electricity production capacity.

The flow sheet of a pumped storage and electrical generation scheme is shown in figure 24:

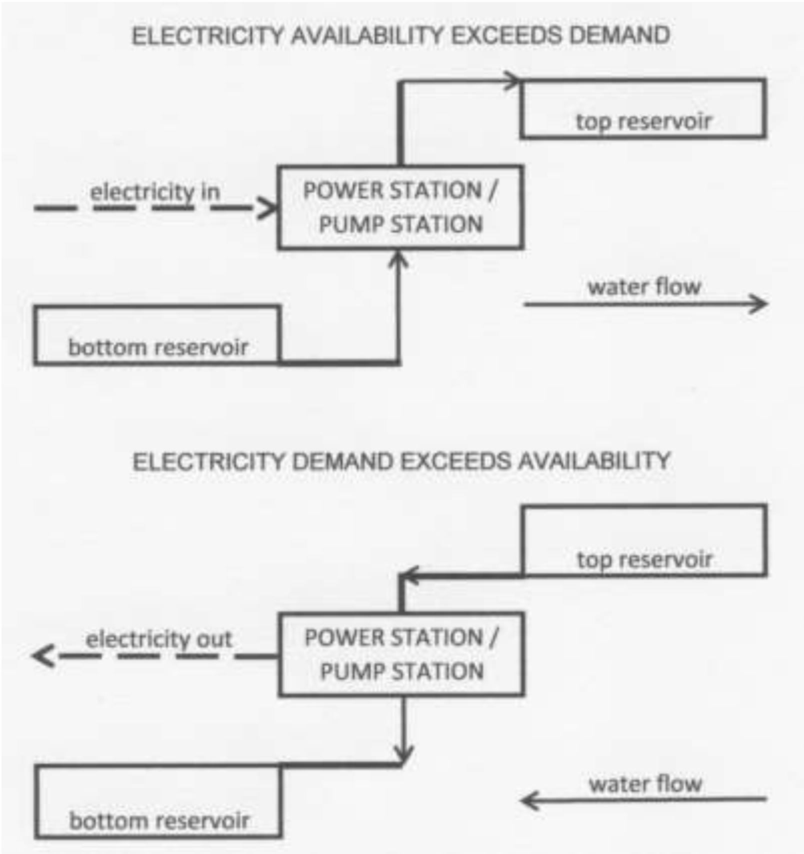

Figure 24 – FLOW SHEET OF A TYPICAL PUMPED STOAGE SCHEME.

2.10.3 <u>Heat Energy Storage</u>.

This was mentioned in section 2.8.3 when covering Contracted Solar Power. A typical layout is shown in figure 25. At night time, liquid salt is pumped from the hot tank, through the steam generator and discharged into the cold tank

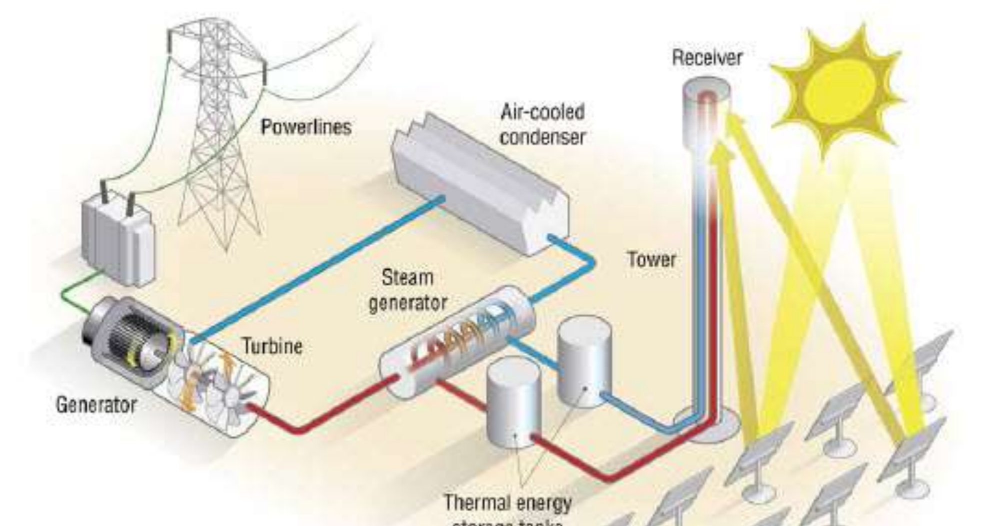

Figure 25 - A TYPICAL HEAT ENERGY STORAGE AND GENERATION FACILITY.

PART 3.

THE TRANSMISSION AND DISTRIBUTION OF ELECTRICITY.

3.1 INTRODUCTION.

In part 2, it was seen how electricity was produced both with and without intermediate storage. This part deals with getting the electricity to the end user and determining how much they use.

In a water distribution system, the size of the water pipe gets smaller closer to the final consumer as the flow rate is less. A typical distribution system is shown below in figure 26.

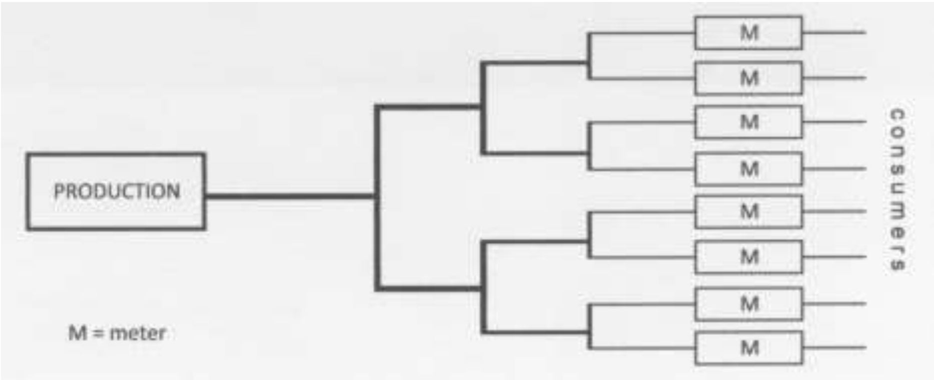

Figure 26 – A TYPICAL SERVICES DISTRIBUTION SYSTEM.

The same type of layout would be found in an electricity transmission and distribution system. It was seen in section 1.5 that it was the electrical pressure (electromotive force) that caused the electrons to move along the conductor – exactly the same as water pressure moving the water along a water pipe.

Transmission of electricity takes place between the power station and the city or town. Distribution takes place within the city or town.

If a water pipe is level and closed off at each end (so there is no movement of water in the pipe); the pressure at one end will be exactly the same at the other end. If the water is moving along the pipe then the pressure at the end to which the water is moving; will be lower. This is shown in figure 27:

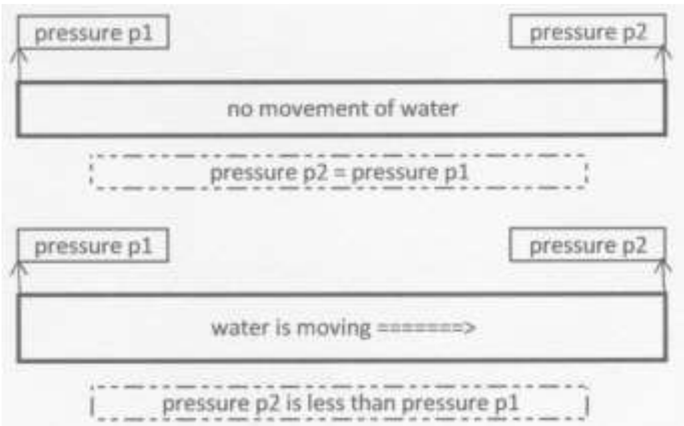

Figure 27 – SHOWING THE IMPACT ON THE PRESSURE OF WATER MOVING ALONG A PIPE.

The difference in pressure is called the pressure drop. This is caused by the friction of the water moving inside the pipe. The higher the flow rate, the higher the friction as the higher the pressure drop.

Exactly the same happens in conveying electricity along a conductor. It was seen the section 1.2.3 that certain "elements with a high ability to conduct electricity are called **conductors**". However, they are not perfect conductors – there is some resistance to the movement of the electrons along a cable etc. made of these elements. It is this resistance to the flow of electricity that would result in a voltage drop across the conductor. In figure 26, replace the word "*pressure*" with "*voltage*" and the word "*water*" with "*electricity*" and one can see the effect.

The flow of water along a pipe can be measured in litres per second. In the same way, the flow of electrons along the conductor can be measured. This rate of flow is called the amperage and is measure in amperes. These are usually shortened to amps and shown by the symbol I.

THE SYMBOL "A" IS NOT USED TO REPRESENT AMPERES AS AN OLD UNIT OF MEASUREMENT CALLED THE ANGSTROM WAS GIVEN THE SYMBOL "A" AND TO AVOID CONFUSION, ANOTHER SYMBOL FOR CHOSEN FOR AMPERES.

As indicated above, the higher the flow rate of water in a pipe, the higher the friction. It is exactly the same with electricity. Therefore trying to increase the current to transfer more energy to the consumer will result in more resistance to the flow of the electricity.

The ability of a material to conduct electrical is called the Electrical Conductance and called "EC" for short. Therefore the higher the conductance, the "easier" the material allows the movement of the electric current. The opposite effect is called the resistance (with symbol R) and is measured on Ohms.

The voltage drop along a conductor can be calculated by the formula: $V = I R$. From this it can be seen that the lower the resistance (the higher the electrical conductance); the lower the voltage drop for a given current. That is why it was mentioned earlier that metals with a high conductance such as copper and aluminium are used to carry electricity.

The power (or energy) carried by a conductor is measured by multiplying the voltage by the amperage. The unit of power is the Watt - with symbol W. This is shown in the following formula:

$$W = V \times I$$

One can see that if one wants to increase the power being supplied by that conductor, one can increase the voltage (V) or the current (I) or both. It was seen above that increasing the current increase the "friction" in the conductor and therefore the voltage drop. It was seen in section 1.3 that energy cannot be destroyed – it can be converted from one form into another form. In this case, the "lost" energy is converted into heat. It is advantageous to minimize this heat loss.

This heat loss may be calculated by the formula

$$W = I^2 R.$$

From the formula, it can be seen that the heat loss is directly proportional to the resistance – in other words **twice the resistance = 2 x the heat loss**. The heat loss is proportional to the SQUARE of the current – in other words **twice the current = 4 x the heat loss.**

Referring to the formula W = V x I, it may now the seen that in order to minimize loss of energy through heat generated in the conductor; it is better to increase the voltage instead.

3.2 THE ELECTRICAL TRANSFORMER.

It was seen above, that to increase the electrical power carried by a conductor, it was better to increase the voltage. This is done by using a transformer.

A **transformer** is an electrical device which, by the principles of electromagnetic induction, transfers electrical energy from one electric circuit to another, without changing the frequency. The energy transfer usually takes place with a change of voltage and current. Transformers either increase or decrease AC voltage. Figure 28 gives an idea of what the inside of a transformer looks like. This is for a single phase. The three phase transformer would have three separate circuits. Transformers of this type only work with an alternating current.

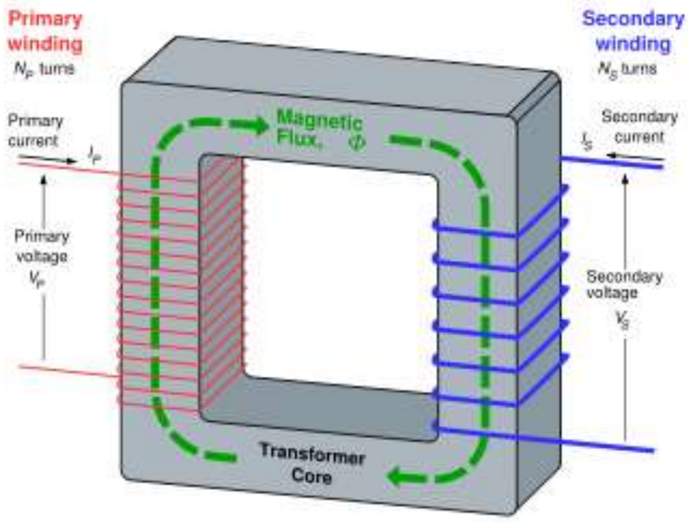

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Figure 28 – SHOWING THE PRINCIPLE OF A TRANSFORMER.

Transformers are used to either increase the voltage OR to decrease it. In figure 29, it may be seen that the secondary windings (the output) has fewer turns of wire and therefore the voltage is lower

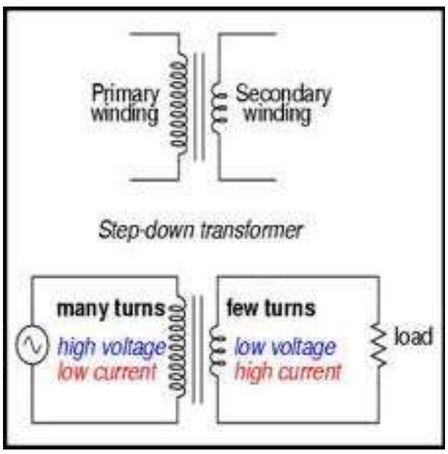

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Figure 29 – SHOWING THE PRINCIPLE OF A STEP-DOWN TRANSFORMER.

The transformer where the output voltage is lower than the input voltage is called a “Step Down Transformer”. Where the output voltage is higher than the input voltage, it is called a “Step Up Transformer”.

Ignoring any losses through heat etc., the power input equals the power output. Therefore as the voltage is reduced, the current is increased. This is seen in the formula below where i = input and o = output:

$$V_i x\ I_i = V_o x\ I_o$$

3.3 USE of TRANSFORMERS in the TRANSMISSION and DISTRIBUTION of ELECTRICITY.

It was seen in section 3.1, that it was better to have a higher voltage (and therefore a lower current) to transmit and distribute electricity. According to the Eskom website, the generators at its power stations generate electricity at 20 000 volts (20kV). According to the generating capacity of the power station and its distance from the main users, the voltage is usually increased to 275kV or 132kV. Even higher voltages are used at times. As these power lines get closer to a city or town, the voltage is reduced to 66kV or 33kV. In the city or town itself, this will generally be reduced to 11kV. For distribution to houses etc., this will be reduced further to 380volts.

At each change in voltage, transformers are used. In figure 26, it was seen that the lines got thinner as one got closer to the consumer. *For water distribution, the thickness of the line would represent the size of the water pipe*. For electricity, the thickness of the line who represent the voltage – thicker = higher.

Voltages of 11kV and 22kV are usually referred to as Medium Voltage (MV). Voltages of 33kV and higher are referred to as High Voltage (HV).

3.4 THE TRANSMISSION OF ELECTRICITY.

As indicated in 3.1, the transmission of electricity takes place between the power station and the city or town. Because of the high voltages involved, overhead wires would be used.

These structures are called “pylons” and are made in various layouts, but all serve the same purpose. The pylons carrying power lines with a higher voltage are larger.

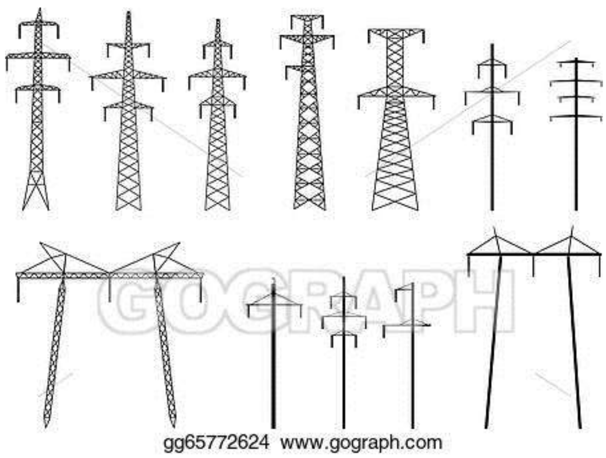

Figure 30 – EXAMPLES OF DIFFERENT PYLON CONFIGURATIONS.

The material used for the overhead powerlines is usually aluminium. Although not as good a conductor as copper, it is much lighter. Sometimes there is a steel core for strength.

Pylons have ceramic or glass **insulators** to support the overhead lines so the **pylon** itself does not become 'live'. An example is shown in figure 31 below:

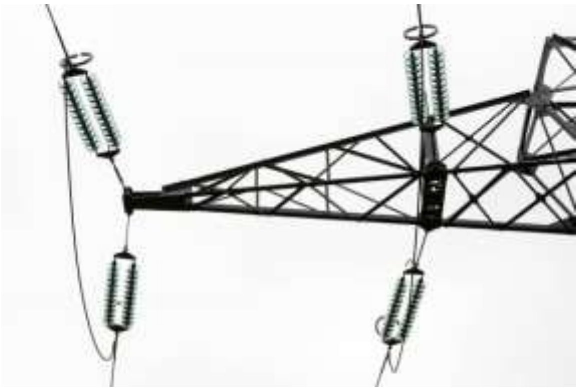

Figure 31 – EXAMPLE OF A PYLON INSULATOR.

3.5 THE DISTRIBUTION OF ELECTRICITY.

It was seen above that the transmission of electricity would generally be by overhead wires. In contrast, the distribution of electricity can be by the following means:

1. by overhead wires;

2. by underground cables.

3.5.1 The Distribution of Electricity by Overhead Wires.

This would be similar to the transmission except that with lower voltages, the pylons would be smaller and will often be a single pole.

3.5.2 The Distribution of Electricity by Underground Cables.

There are various types of underground cables in use.

1. Oil filled in a sleeve. This is not often used due to cost.

2. Paper Insulated Lead Covered (PILC). Sometimes used for 11kV;

3. PVC and Steel Wire Armoured (PVC/SWA/PVC). This is the most commonly used type.

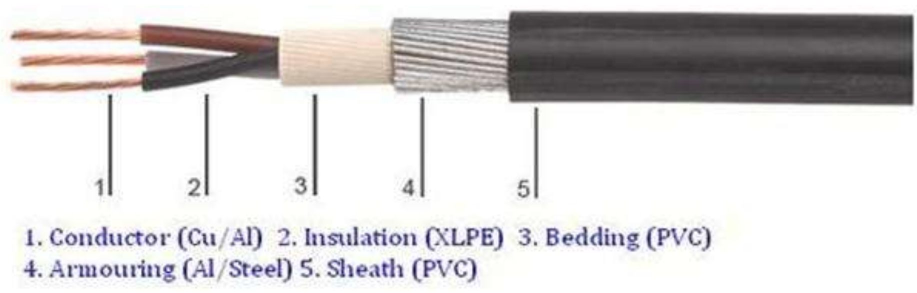

Figure 32 – PVC/SWA/PVC ELECTRICITY CABLE.

3.6 ON SITE DISTRIBUTION OF ELECTRICITY.

The supplier of electricity will feed into the main distribution board of the user. They may feed to the site at 11kV and then supply the user at 11kV or at 380V. In either case, they will have their own circuit breakers, metering devices etc. In the first case, the user would have their own transformer.

The user will have their own main distribution board from which the various points of usage will be fed. For the larger user, there will usually be a ring main around the site at 11kV. At selected points on the site, there will be transformers and sub-Distribution Boards. These sub-Distribution Boards will then supply the various items of equipment, including lighting, with electricity.

An example of such a ring main system is shown below in figure 33. The RMU's are Ring Main Units – think of them as switches. The idea of a ring main around the site is that if one part of the circuit is damaged then the electricity may be supplied from the undamaged side. A typical operating mode could be:

Transformer 1 is fed from point A by RMU 1;
Transformer 2 is fed from point A by RMU 1 and RMU 2;
The link between RMU 2 and RMU 3 is switched off;
Transformer 3 is fed from point B via RMU 3.

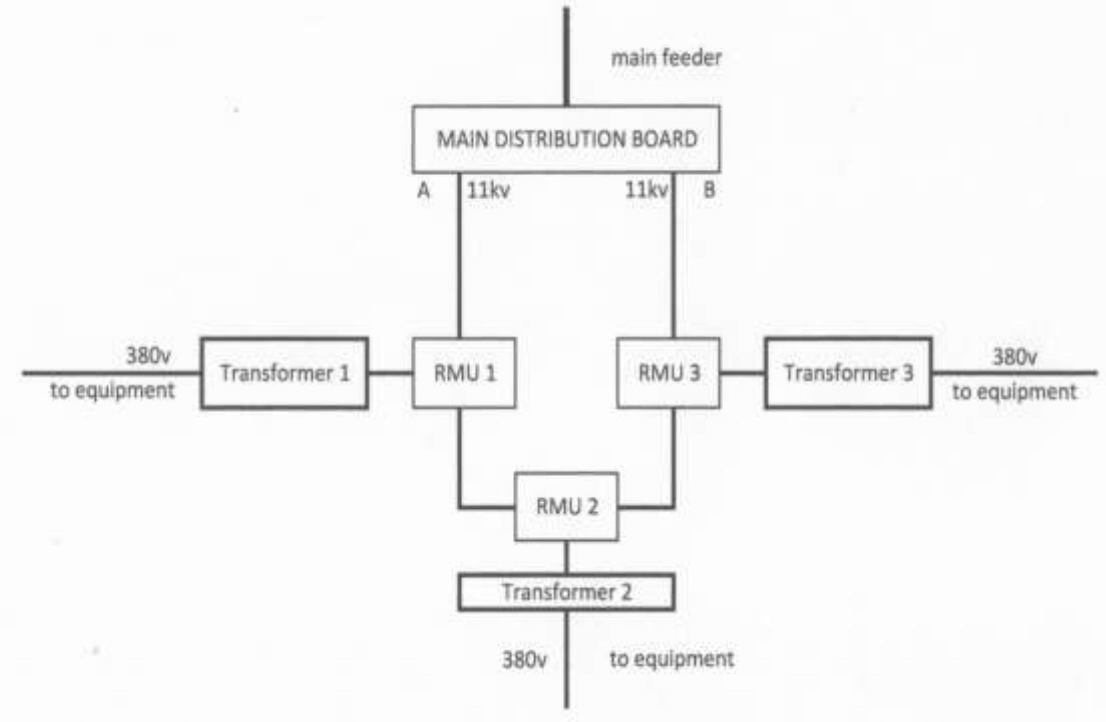

Figure 33 – SHOWING A TYPICAL 11kV RING MAIN SUPPLY AROUND THE SITE.

The main distribution board, the RMU's and the Transformers would all have an earthing point in the ground. This is for safety.

A small site could be fed directly from the main distribution board.

3.7 VOLTAGES IN THREE PHASE AND SINGLE PHASE ELECTRICITY.

As mentioned, the two forms of alternating current are Three Phase and Single Phase. The modern trend is to supply houses with single phase electricity.

The question is: how do you get single phase electricity from a three phase supply. This will be shown below.in figure 34. The electricity distributed in residential and industrial areas is known as **three phase four wire.** The fourth wire in the neutral wire.

The difference in voltage between the phases is 380 volts, while the difference between a phase wire and the neutral wire is 230 volts. This is where the houses get their single phase 230 volt supply. This is shown schematically in figure 33 below:

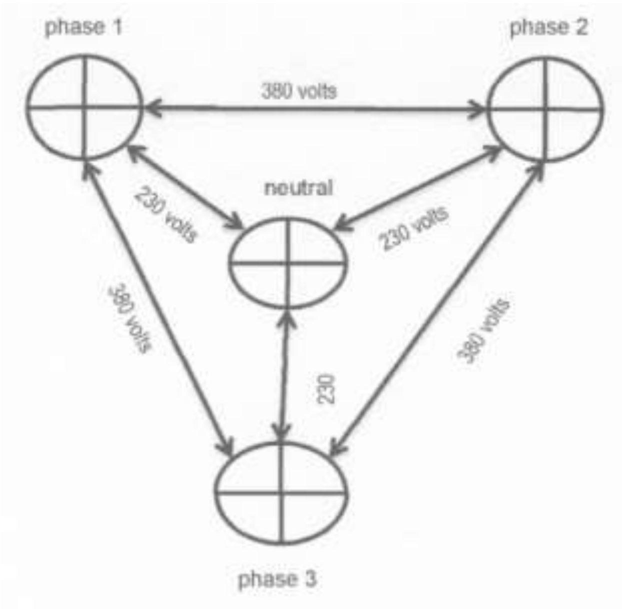

Figure 34–SHOWING THE PHASE TO PHASE VOLTAGE AND THE PHASE TO NEUTRAL VOLTAGE.

For transmitting the same amount of power at the same voltage, a three phase transmission line requires less conductor material than a single phase line. The three phase transmission system is therefore cheaper. For a given amount of power transmitted through a system, the three phase system requires conductors with a smaller cross-sectional area.

The comparison of three phase and single phase electricity will be dealt with in the next section on electric motors and their switchgear.

Earlier the colours of the wires used in the 230 volt system where Brown (live), Blue (neutral) and Yellow/Green earth**.**

It is very important that the wires be connected to the correct terminals in a switch and the correct part of a plug – this is to ensure that it is the Brown (live) wire that is switched off at the switch and not the Blue (neutral) wire. Otherwise the item at the end of the wire would still be alive.

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PART 4.

ELECTRIC MOTORS AND THEIR SWITCHGEAR.

4.1 INTRODUCTION.

Part 2 dealt with the production of electricity and part 3 dealt with the transmission and distribution. The electricity will now be used to perform work.

Certain items of equipment such as computers, printers and scanners use small motors using a low voltage direct current. These units will have their own transformers and rectifier for converting the alternating current into direct current. They will not be considered further.

Most of the electric motors on a water treatment works or a wastewater treatment works will use alternating current and 3 phase electricity. Even motors as small as 0.4kW, will use 3 phase electricity.

4.2 COMPONENTS OF AN ELECTRIC MOTOR.

It was seen in section 2.6 that mechanical energy was converted into electrical energy by a generator or alternator. The electric motor works the other way round by converting electrical energy into mechanical energy in order to do work.

The most common type of electric motor used for water and wastewater applications is the **induction** motor. This type of motor is similar in construction to the alternator in that it has a stator that it supplied with electricity and rotor that rotates inside the stator. The induction electric motor is so-called because the electric current in the rotor needed to produce torque is obtained by electromagnetic induction from the magnetic field of the stat or winding. An induction motor has no electrical connections to the rotor. The main components of an induction electric motor are shown in figure 35 below:

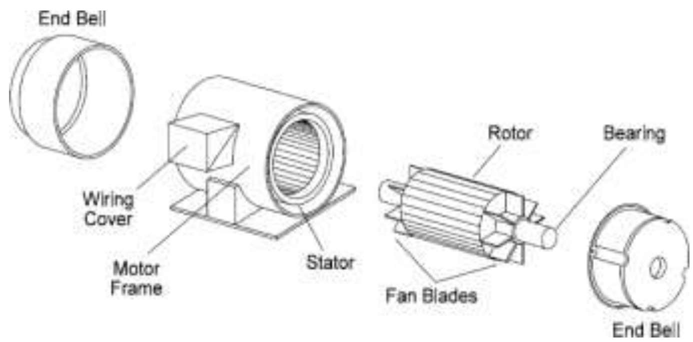

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Figure 35 – MAIN COMPONENTS OF THE INDUCTION ELECTRIC MOTOR.

4.3 SINGLE PHASE ELECTRIC MOTORS.

A single phase induction electric motor will not start by itself is switched on as there is no moving magnetic field to make it turn. One way to overcome this is to use a capacitor to give the rotor a “kick” to get it turning. Once it is turning, then the capacitor is usually switched out of the circuit. How all this works, is a bit complicated, so it will not be covered here.

If a single phase induction will not start, it may need a new starting capacitor – they do not last for ever.

As single phase induction motors are usually of low power output (less than 1kW). They can be started simply by switching on the circuit. This is known as Direct-on-Line starting or DoL starting.

4.4 THE CONCEPT OF TORQUE.

It is necessary at this stage to introduce the concept of torque. This concept is important when considering the starting of electric motors.

Torque can be thought of as a twist to an object around a specific axis. One uses torque to turn the handle or knob on a door to open the door. Another example is using a spanner to tighten a nut on a bolt as shown in figure 36. Torque is measure in Newton-Metres (N-m).

Figure 36 – SHOWING THE CONCEPT OF TORQUE.

4.5 THREE PHASE ELECTRIC MOTORS.

The three phase induction electric motor has 3 sets of windings in the stator. As seen in section 2.6.3, the 3 phases runs 120 degrees after each other. These are shown as red, blue and green in figure 37.

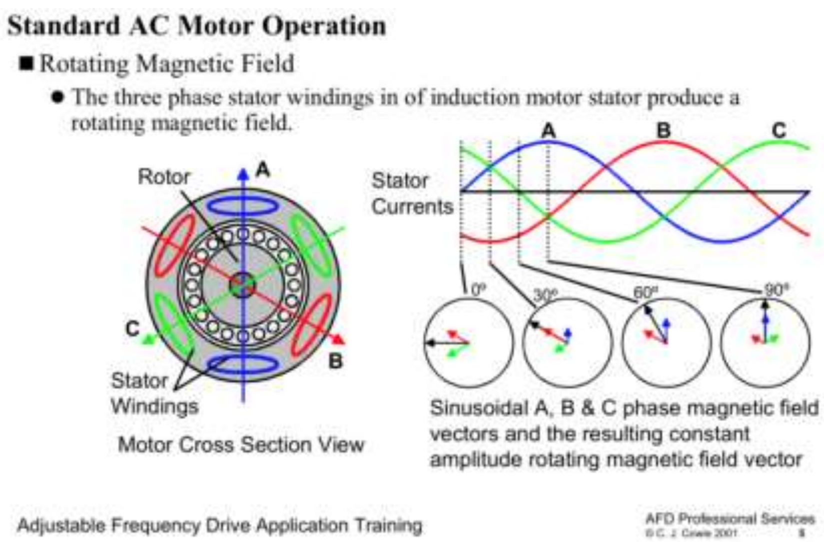
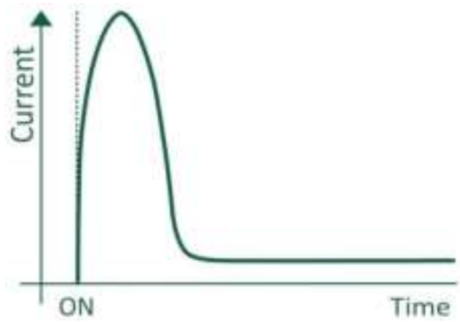


Figure 37– SCHEMATIC OF THE WINDINGS OF THE 3 PHASES IN THE STATOR.

As the 3 phases produce their magnetic field at different times (120 degrees of rotation after each other); a three phase induction motor is self-starting. At the starting time, the induction motor draws 5 to 7 times higher current than rated current. This is not a problem for small 3 phase induction motors, so they can be started Direct-on-Line, just by pressing a button or switching a switch. Figure 38 gives an indication of the starting current of an induction electric motor



Netio Products a.s.

Figure 38 – A TYPICAL STARTING CURRENT PROFILE

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As may be seen, there is a sudden rise in the current drawn up to a peak and then decreasing when the motor has reached its operating speed.

The Direct-on-Line starting is usually only used with motors of less than 11kW rating. For larger electric motors, it is necessary to use a method that will limit the starting current. The most common method is the Star-Delta starting. In three phase wiring, there are two ways of connecting up the phases. Earlier in section 3.7, it was seen in figure 34 that the phase to phase voltage was 380 volts while the phase to neutral voltage was 230 volts.

The term "STAR" is used here, sometimes the term "WYE" is used as the "Y" shape is used in electrical drawings.

The Star-Delta starting makes use of this property. It is seen in figure 39, that if the windings are temporarily connected using the star point (or neutral point, then the voltage across each winding is 230 volts and in the example shown, the current would be 10 amps across each winding. **This current is NOT the peak current as shown in figure 37 above, but is the current in the flat part of the curve – that is after the motor has reached its normal operating speed.**

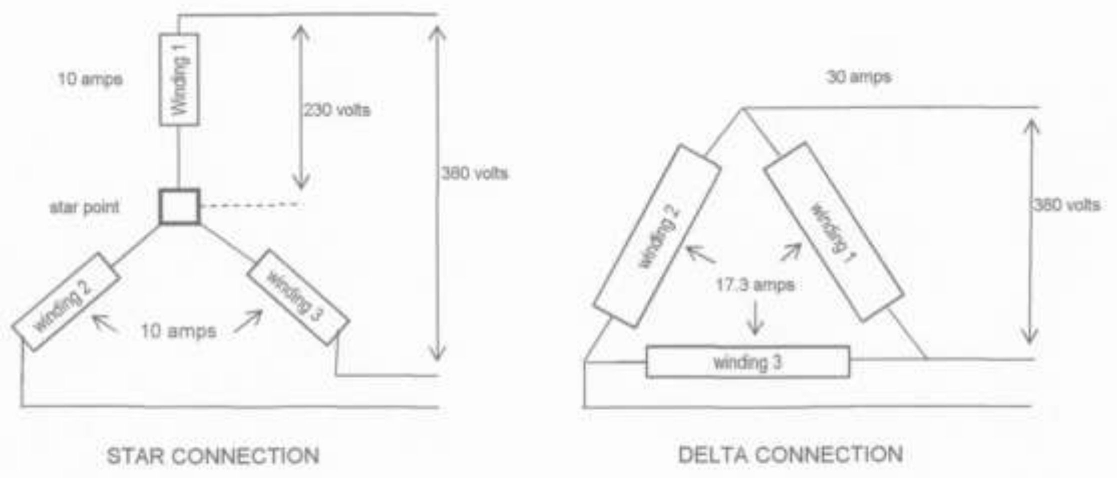

Figure 39 – SHOWING STAR AND DELTA CONNECTIONS.

The star point as shown in the left hand layout is situated in the electrical panel. The electric motor feed cable will have three conductors for the three phases.

A three phase motor can be operated in star mode, but the torque produced by the electric motor is only about one third of the torque produced when running in delta mode.

It is possible to obtain the advantage of a lower starting current and also the get the advantage of the higher torque during normal operation. This is done by starting the electric motor in star mode and then switching over to delta mode. This will be described in more detail below in section 4.7.6.

4.6 COMPARISON OF SINGLE PHASE AND TREE PHASE ELECTRIC MOTORS.

There are many advantages in using three phase motors over single phase motors. These include:

1. the delivery of power and torque by the motor is much more uniform in a three phase system than in a single phase system;

.2. for the same power output, the three phase motor is smaller;

3. a three phase induction motors is self-starting whereas single phase motor has no starting torque and requires an auxiliary means for starting;

4. three phase motors are more efficient in terms of power consumed;

5. three phase motors are very robust, relatively cheap, and require little maintenance compared with single phase motors;

4.7 ELECTRICAL BOARDS (PANELS).

4.7.1 Introduction.

The main electrical board is used to accept, meter and distribute the electricity supply to the various usage points. This is shown in simplified form in figure 40.

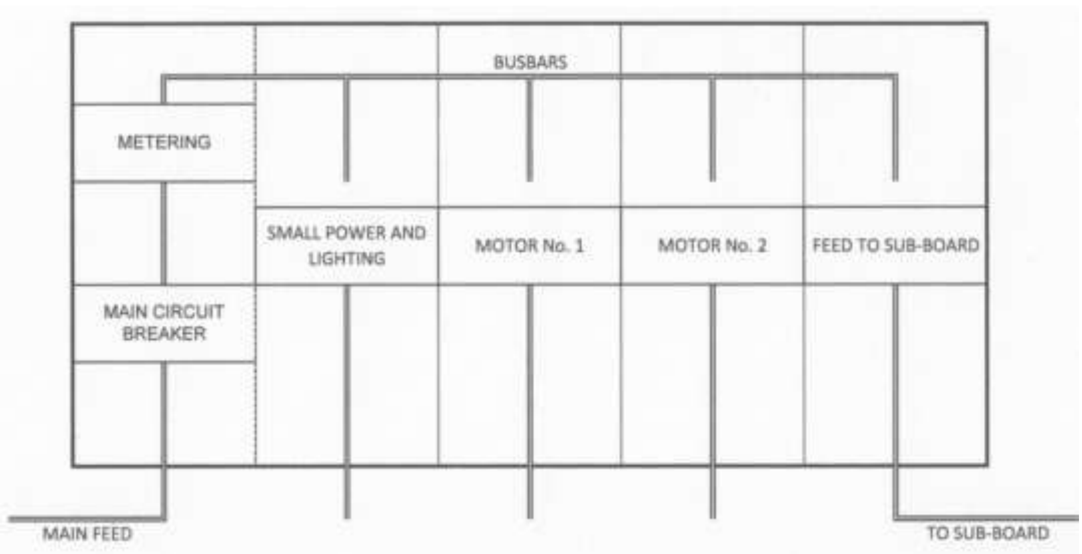

Figure 40 – SCHEMATIC OF A SIMPLE ELECTRICAL DISTRIBUTION BOARD.

4.7.2 Main Circuit Breaker and Metering.

The main circuit breaker will trip (switch off) if there is a major overload somewhere in the system. The different units of the board will have their own circuit breakers that should trip out only that section of the board and leave the rest of the board operational.

The subject of metering will be covered in Part 5.

4.7.3 Small Power and Lighting.

This part of the board will supply power to lighting circuits, small power usage such as extraction fans and 15 amp plugs. These will all operate at 230 volts. As seen earlier, this voltage is available between one phase and neutral. The various circuits will have their own circuit breaker to trip (switch off) if there is a fault in the wiring or in the item being supplied with electricity.

The circuit feeding the 15 amp three pin plugs will be fitted with an earth leakage protection system. This unit monitors the current in the live and the neutral wires. Where the neutral wire carries a lower current than the live wire then this indicates that some electrical current is leaking to earth. Hence the name earth leakage protection. They are usually set to trip the circuit when the difference in current between the live and the neutral is 30 mA. The main purpose of earth leakage protectors is to prevent injury to humans due to electric shock.

It is always a good idea to test the unit by pressing the test button at regular intervals. This is often the duty of the Safety Representative for the area. To avoid complaints from the users, any testing should be done with their prior knowledge so that they can switch off computers etc. first.

4.7.4 Large Power Panels.

In the simplified layout of an electrical board above, there are two electric motors being fed from this board. These panels will usually contain the following items on the front face of the panel:

1. circuit breaker;

2. volt meter – sometimes switchable between the various phases;

3. three ammeters – one per phase;

4. running hour meter – to indicate the number of hours that the electric motor has been running;

5. duty selector switch – to select which electric motor starts first and which is the standby motor that would start if needed due to high water level, duty motor tripping etc.

The panels would usually contain the following items inside the panel:

1. electrical contactors – to make sand break the electrical circuit;

2. control circuits – to operate the electrical contactor;

3. circuit breakers – to trip if excessive current is drawn by the electric motor;

4. the star / delta starting system;

5. protection devices – these will be covered below in section 4.7.8.

4.7.5 Electrical Contactors.

The starting equipment for an electric motor will be fitted inside an electrical panel. In small power and lighting circuits, pushing a button or operating a lever closes the contacts and allows the current to flow. This enables the electric motor to start or the lights to come on.

In all other applications, a contactor is used. This is an electrically controlled switch used for opening and closing of an electrical power circuit. This is necessary because the electrical circuit must be closed (and opened) very quickly. This is to prevent the electrical current jumping from one part of the contactor to the other – this is called “arcing”. This will damage the two parts of the contactor. In addition, it is necessary that all three electrical circuits are closed at exactly the same time.

On pressing the start button, the electrical control circuit is switched on. This provides power to a solenoid. This solenoid is a wire coil that functions as an electromagnet when switched on and this attracts the moving part of the contactor. When the contactor is closed, the electricity goes to the electric motor. This is shown in figure 41. When the stop button is pressed then the control circuit is switched off and the electromagnetic force stops, the spring then opens the contacts and the electricity supply to the motor stops. The red dashed line shows the electricity supply to the electric motor.

The contacts are usually made of copper and often have a silver layer on the face for a longer life.

The control circuit will normally operate on 230 volts.

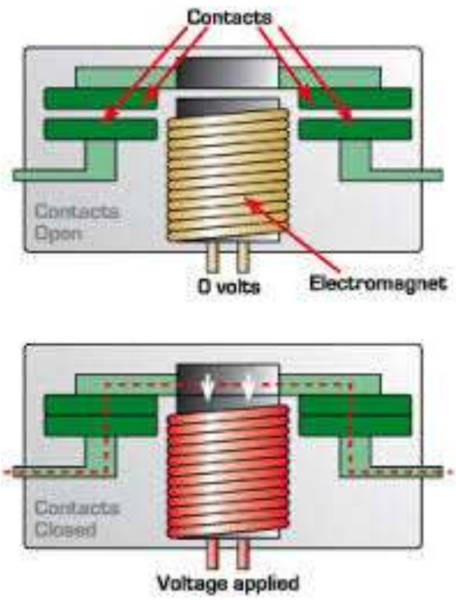

Figure 41 – A SOLENOID OPERATING A CONTACTOR.

4.7.6 The Star/Delta Starting System.

Having seen how the control circuit opens and closes the contactors, one can now see how the system works. The Star/Delta starter consists of three contactors; a timer and a thermal overload. These are seen in figure 42 below. The three phases in this diagram are called Red, Blue and Yellow. The Yellow phase is often called the White phase.

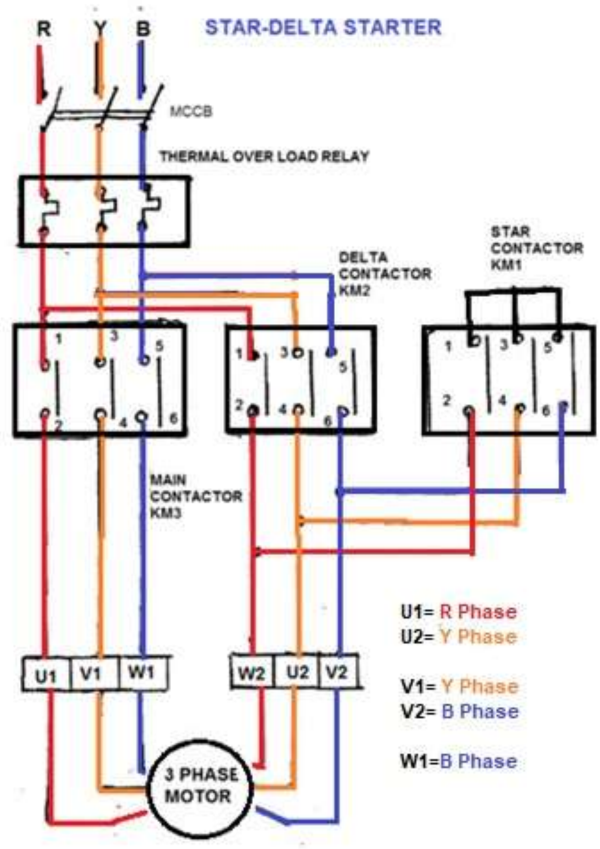

Figure 42 – A TYPICAL STAR/DELTA WIRING DIAGRAM.
(the control circuit wiring is not shown).

On pressing the start button, both the Main Contactor (KM3) and the Star contactor (KM1) are closed by the control circuit and the electric motor starts. After the preset time, the Star contactor (KM1) opens and simultaneously the Delta contactor (KM2) closes. The electric motor is now running in Delta mode and is producing full power and full torque. The length of time that the electric motor runs in Star mode depends on many factors, but is usually 5 to 10 seconds.

The thermal overload relay shown in figure 42 will be covered later in the section on motor protection.

4.7.7 Distribution to other Electrical Boards.

Usually electrical power is required at other points on the site, so they would be fed from this point.

If large amounts of power are required on a fairly large site, then a ring main distribution system (as covered in section 3.6 would be used.

4.7.8 Protection Equipment.

In the small power and lighting panel, the earth leakage protection was covered. In the large power panel, there are various forms of protection of the electric motor and its electricity supply. This is necessary to prevent damage to the electric motor and to minimize the possibility of fire should a fault arise in the electric motor or its control panel. These protection devices usually include the following:

1. excessive current – if the electrical current exceeds the design figure, then the thermal overload would interrupt the electrical supply. As seen in figure 38, immediately on starting, the electrical current is very high before dropping to its normal value when the motor is at its operating speed. In order to protect electrical motors, especially the larger ones, the thermal overload will limit the number of starts per hour. In the case of a large motor, this could be a maximum of 5 starts per hour. The thermal overload takes times to cool down and reset itself;

2. Under voltage protection – if the voltage drops at any time, then the current drawn by the electric motor will increase. All conductors, including those inside the electric motor have some resistance and so some heat is generated at all points in the electrical circuit. The heat generated is proportional to the SQUARE of the current. If the voltage drops by say 10%, then the current will rise by about 10% but the heat generated will rise by about 21%. Under these conditions, the control circuit will be interrupted and the main contactor will open thus breaking the electrical supply to the electric motor;

3. single phase protection – if one of the phases is interrupted for any reason, the electric motor will not run and excessive heat will be created in the winding fed by the other two phases. Again the control circuit will be interrupted and the main contactor will open thus breaking the electrical supply to the electric motor.

4.8 ELECTRIC MOTOR SPEED.

The speed of rotation of an electric motor depends on two factors:

1. the frequency of the electricity supply. In South Africa, the standard frequency is 50 Hz (cycles per second). The number of cycles per minute would then be 50 x 60 = 3 000;

2. the number of poles in the motor. The minimum number of poles is 2. The rotational speed of the motor would in theory be:

$$\frac{3\,000 \times 2}{\text{No of poles}} = 3\,000 \text{ revolutions per minute (rpm)}$$

TABLE 2 -THEORETICAL ROTATION SPEED OF ELECTRIC MOTORS

No of poles	Theoretical Rotational Speed rpm
2	3 000
4	1 500
6	1 000

In practice there is some slip in the motor in that it runs slightly slower than the theoretical speeds given above in table 2. This generally varies from about 1% in large motors to about 5% in small electric motors.

TABLE 3 - TYPICAL ROTATION SPEED OF ELECTRIC MOTORS

No of poles	Typical Rotational Speed rpm
2	2 950 to 2 980
4	1 420 to 1 480
6	950 to 980

There are two speed motors such as 4 pole and 6 pole combined in one enclosure. These are useful in anoxic and anaerobic zones in the activated sludge process. The lower speed would generally be used for most of the time. The higher speed could be used for say one hour per day to see if excessive settling of sludge is taking place. If so, then the higher speed could be used for longer or more frequently. As these would be lower power motors, direct-on-line starting would be used. The switch gear would be more complicated in the control panel as there would be two sets of wires going to the electric motor. One set would be for the 4 pole windings and a separate set for the 6 pole windings.

There are also variable speed motors. These required sophisticated electronic control systems that fall outside the scope of this guide.

4.9 CLASSIFICATION OF ELECTRIC MOTORS IN TERMS OF OPERATING CONDITIONS.

Electric motors may be classified in terms of the conditions under which they operate:

1. Drip Proof (DP) – these have open enclosures. These motors are suitable for indoor use and clean atmospheres. Ventilator openings are designed to prevent liquids and solids from entering the machine from an angle of 0 to 15° from the vertical;

2. Totally Enclosed Fan Cooled (TEFC) – these may be used outside without protection from the rain. They must, however, not be flooded;

3. Explosion-Proof (XPRF) Motors are completely enclosed to withstand an internal explosion of gas or vapour - the motor frame will not rupture or burst. These would be used near sludge digesters or other hazardous environments;

4. Submersible - these are designed to operate under water and are usually attached to a pump and placed in a sump to pump water, wastewater or sludge. They must run only under water to prevent them from overheating;

5. Immersible – these can operate in the air, partly submerged or totally submerged.

4.10 INGRESS PROTECTION RATING (IP).

The IP rating classifies and rates the degree of protection provided by mechanical casings and electrical enclosures against intrusion, dust, accidental contact, and water.

The first digit indicates the level of protection that the enclosure provides against access to hazardous parts (e.g., electrical conductors, moving parts) and the ingress of solid foreign objects.

The second digit indicates the level of protection that the enclosure provides against harmful ingress of water.

TABLE 4 – MEANING OF FIRST DIGIT IN IP RATING.

DIGIT	DEFINITION / SIZE	DETAIL
1	>50mm	Any large surface of the body, such as the back of a hand, but no protection against deliberate contact with a body part.
2	>12.5mm	Fingers or similar object.
3	>2.5mm	Tools, thick wires, etc.
4	>1.0mm	Most wires, slender screws, large ants etc.
5	Dust Protected	Ingress of dust is not entirely prevented, but it must not enter in sufficient quantity to interfere with the satisfactory operation of the equipment.
6	Dust - tight	No ingress of dust; complete protection against contact.

TABLE 5 – MEANING OF THE SECOND DIGIT IN IP RATING.

DIGIT	DEFINITION	DETAIL
1	Dripping water	Dripping water (vertically falling drops) shall have no harmful effect on the specimen when mounted in an upright position onto a turntable and rotated at 1 RPM.
2	Dripping water when tilted at 15^0	Vertically dripping water shall have no harmful effect when the enclosure is tilted at an angle of 15° from its normal position.
3	Spraying water	Water falling as a spray at any angle up to 60° from the vertical shall have no harmful effect.
4	Splashing of water	Water splashing against the enclosure from any direction shall have no harmful effect.
5	Water jets	Water projected by a nozzle (6.3 mm) against enclosure from any direction shall have no harmful effects.
6	Powerful water jets	Water projected in powerful jets (12.5 mm) against the enclosure from any direction shall have no harmful effects.

4.11 POWER FACTOR AND ITS CORRECTION.

4.11.1 Introduction.

POWER FACTOR is the ratio between the useful (true) power (kW) to the total (apparent) power (kVA) consumed by an item of alternating current electrical equipment or a complete electrical installation. It is a measure of how efficiently electrical power is converted into useful work output. The ideal power factor is unity, or one. Anything less than one means that extra power is required to achieve the actual task at hand.

4.11.2 Lagging and Leading power factors.

It has been seen earlier that both the voltage and the current form a sine wave pattern.

What has not been considered is whether the two patterns coincide. Where most of the electrical power is being used by induction motors the patterns are the same, but the voltage pattern lags the current. The difference is known as the phase angle and is usually indicated by the symbol ϕ. This is shown in the centre graph in figure 43.

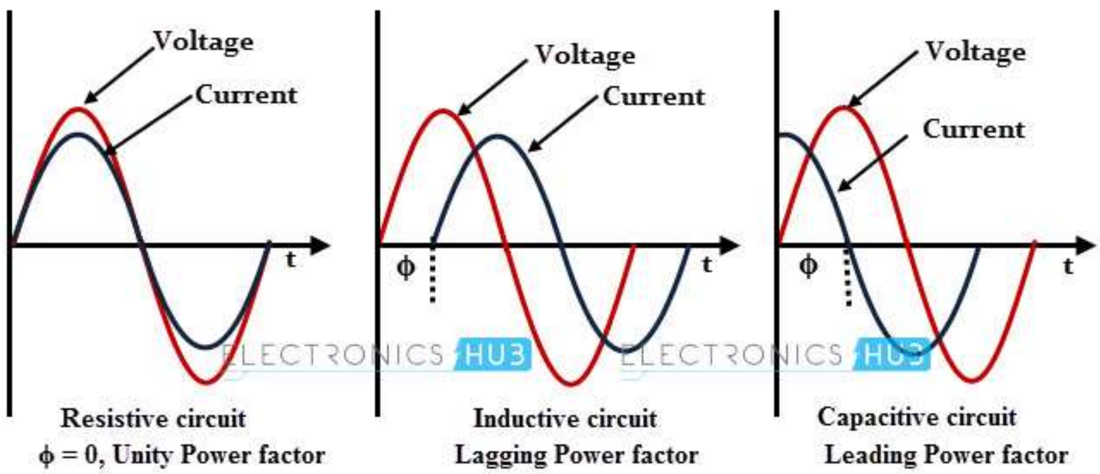

Figure 43 – SHOWING COINCIDENT, LAGGING AND LEADING POWER FACTORS.

In induction motors, the power factor varies according to the load as shown in figure 44. It may be seen that when the load is low then the power factor is very poor. It improves as the load increases reaching a value of about 0.8 at 100% load.

The question is: Does this matter?

The answer is yes is does. This will be seen in part 5 under Metering. How to improve the power factor will be covered below.

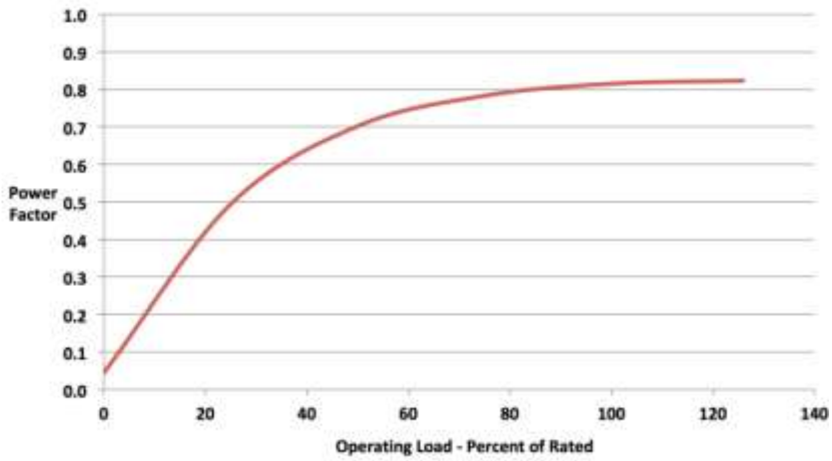

Figure 44 – SHOWING HOW POWER FACTOR VARIES WITH LOAD.

4.11.3 <u>Power Factor Correction (Improvement).</u>

It may be seen in the right hand graph of figure 43 that in a capacitive circuit, the voltage leads the current. This is the opposite in the inductive circuit. This indicates the possibility of using a capacitive circuit to “balance” the inductive circuit. This is in fact, **exactly how it is done**. Figure 45 shows a simple line diagram of how the capacitors are connected across the three phases.

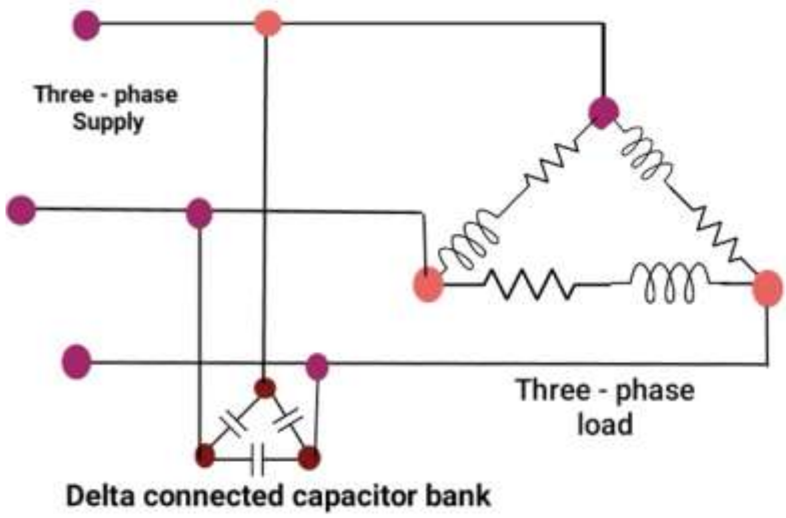

Figure 45 – SHOWING HOW CAPACITORS ARE CONNECTED ACROSS THE PHASES.

Exactly how the capacitors produce the effect of the voltage leading the current is rather complicated and falls outside the scope of this guide.

The capacitor with its voltage leading characteristic is used to “balance” the voltage lagging characteristic of the induction electric motor. The size of the capacitor depends on the power rating (size) of the electric motor. Figure 46 shows the inclusion of the capacitor in the electrical circuit help bring the voltage and the current into “line with each other”. The left hand part of the circuit is the power supply while the right hand side is the electric motor. The zigzag line indicates the resistance of the electricity cables and the curly line indicates the inductance of the motor. These are the universally accepted symbols for these items in an electrical circuit.

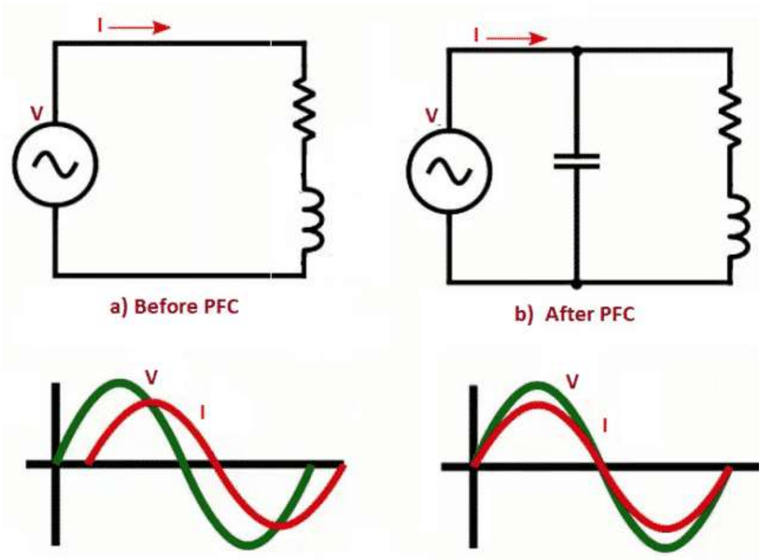

Figure 46 – SHOWING HOW THE CAPACITOR HELPS BRING THE VOLTAGE AND CURRENT INTO LINE WITH EACH OTHER.

It was seen in figure 44 that the power factor of the motor varies as the load on the motor varies. Therefore the amount (size) of the capacitor needed for powered factor correct will vary according to the motor load.

One way to overcome this is to do some power factor correct at each large motor and then do the final power factor correction at the point in the main electrical board where the metering is situated and where the main electrical feed is. The best layout is where the final power factor correction at the main board is automatic. This will involve a number of capacitors of different sizes and a control system that switches the various capacitors in and out as necessary. Exactly how this works is quite complicated and falls outside the scope of this guide.

As seen earlier, the typical power factor of an induction electric motor is about 0.8. The usual practice is to correct the power factor to about 0.96. It is possible to improve to 0.98 or even 0.99 but the cost of the capacitors and control equipment normally does not justify the relatively small extra saving.

This is known as **“The Law of Diminishing Returns”.** This means that each small increase in benefit costs more and more.

4.12 OTHER IMPORTANT MATTERS ABOUT ELECTRICAL BOARDS.

Every operation, taking of readings etc. that a Process Controller needs to do in the performing of their duties must take place on the outside of the electrical board.

There must NEVER be a need for a Process Controller to open an electrical panel to perform, any of their duties. The opening of an electrical panel must be carried out ONLY by qualified electricians.

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PART 5.

THE METERING OF ELECTRICITY SUPPLIES.

5.1 INTRODUCTION.

Part 2 dealt with the production of electricity; part 3 with the transmission and distribution of electricity; while part 4 dealt the various uses of the electricity.

Part 5 will deal with the metering of the amount of electricity used and how it will be charged for.

There are usually two types of electricity meters on the main electrical board. These are:

1. the Energy consumption Meter or kWh meter;

2. the Maximum Demand Meter or kVA meter

5.2 THE kWh METER.

The kWh meter is used to show the energy consumed in **kWh** – kilowatt hours. This is kilowatts times hours.

For example, if a kettle with a 2 000 watt element (2kW) is used for 6 minutes (0.1 hours); then the amount of electricity used is 2.0 kW x 0.1 h = 0.2 kWh. This is often referred to as “Units”.

The kWh meter consists of an induction motor connected to a mechanical meter display as shown in figure 47. The kWh meter could also have an electronic display. This meter is usually read once per month by the electricity supply authority.

Figure 47 – MECHANICAL DISPLAY kWh METER

5.3 THE MAXIMUM DEMAND METER.

The Maximum Demand Meter measures the maximum power drawn as is averaged over a period such as 15 or 30 minutes depending on the supply authority. This is also read once per month and is reset every time that the meter is read. They can also be mechanical with two indicating arms or with two digital displays. In both cases, they would show the ongoing demand and the other would show the maximum demand since it was reset.

The maximum demand meter indicates kVA – kilovolt amps

5.4 THE DIFFERENCE BETWEEN kW AND kVA.

The kilowatt is the amount of power that is converted into a useful output. This will occur when the volt sinewave and the current sinewave coincide. When this happens then **volts x amps = watts**.

The problem is that it is only rarely do the volt and current sinewaves coincide due to a number of factors. In the domestic usage with lights, hot water cylinder and stove etc. the difference is small and is ignored. That is why a house only has a kWh meter.

Because the volts sine wave and the current sinewave do not coincide, the amount of APPARENT power drawn is also volts x amps even though the maximum volts and the maximum amps do not occur at the same time as seen in the left hand drawing in figure 48.

Ignore the fact that the maximum of the volts (V) is not the same as the maximum of the current (I) – this is just to make it easier to see.

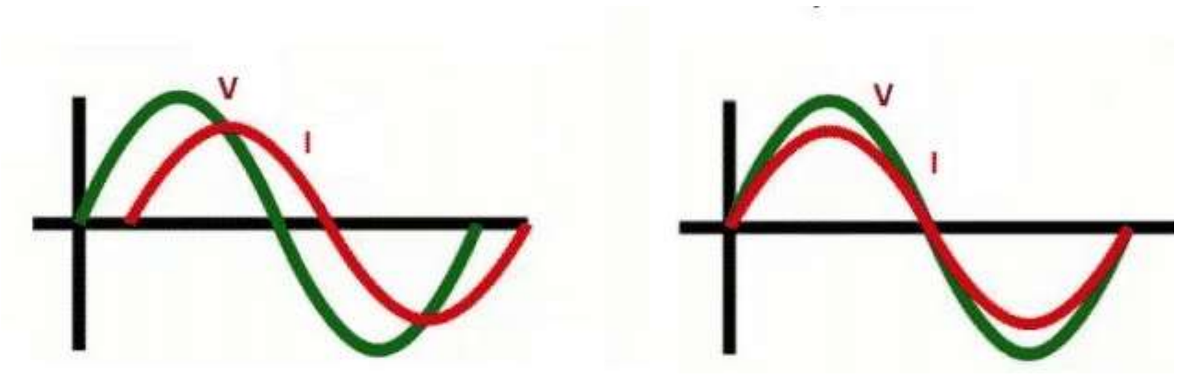

Figure 48 – NON-COINCIDENT (LEFT) AND COINCIDENT (RIGHT) SINEWAVES

The unit of apparent power is the **kilovolt – amp** or **kVA**. In short, this means that the consumer is paying for something that is of no benefit to them.

In section 4.8, the concept of power factor was introduced. Now the impact of the power factor on the maximum demand will be shown.

Example of the impact of improving the power factor:

If the peak useful power demand is 1 000 kW and the power factor is **0.8**; then the maximum demand meter will indicate 1 000 divided by 0.8 = **1 250 kVA**. If the power factor was improved to 0.98; then the maximum demand meter would indicate 1 000 divided by 0.98 = **1 020 kVA**.

THIS IS A SAVING OF 1 250 – 1 020 = 230 kVA. Based on Table 1 of the 2020/2021 Eskom standard tariff schedule; this represents a saving of 230 x R64-55 or **R14 846 per month excl VAT.**

It may be seen that there is a significant saving in improving the power factor from 0.8 to 0.98.It is usually not worth the cost in terms of capacitors, control equipment etc. to improve the power factor beyond 0.98.

5.5 THE POWER FACTOR METER.

This is a useful meter to have but unfortunately is not often installed. This meter gives an indication of how well the power factor correction system is working. The meter should always show a lagging power factor. Electricity supply authorities do not like a like a leading power factor. It can have an adverse effect on the transformer on the feed to the consumer.

A typical power factor meter is shown in figure 49.

Figure 49 – A TYPICAL POWER FACTOR METER

5.6 TIME OF USE TARIFF.

Some electricity supply authorities offer a Time of Use tariff with a higher energy cost during peak times and a lower energy cost during off peak times.

The Time of Use (TOU) periods means time blocks based on the amount of electricity demand during high, mid and low demand periods where the tariff will differ. The TOU periods typically are peak, standard and off-peak periods and differ during in high and low demand seasons.

The high demand season is 1st June until 31st August, while the low demand season is 1st September until 31st May of the next year. The times during which each tariff applies is shown in figures 50 and 51.

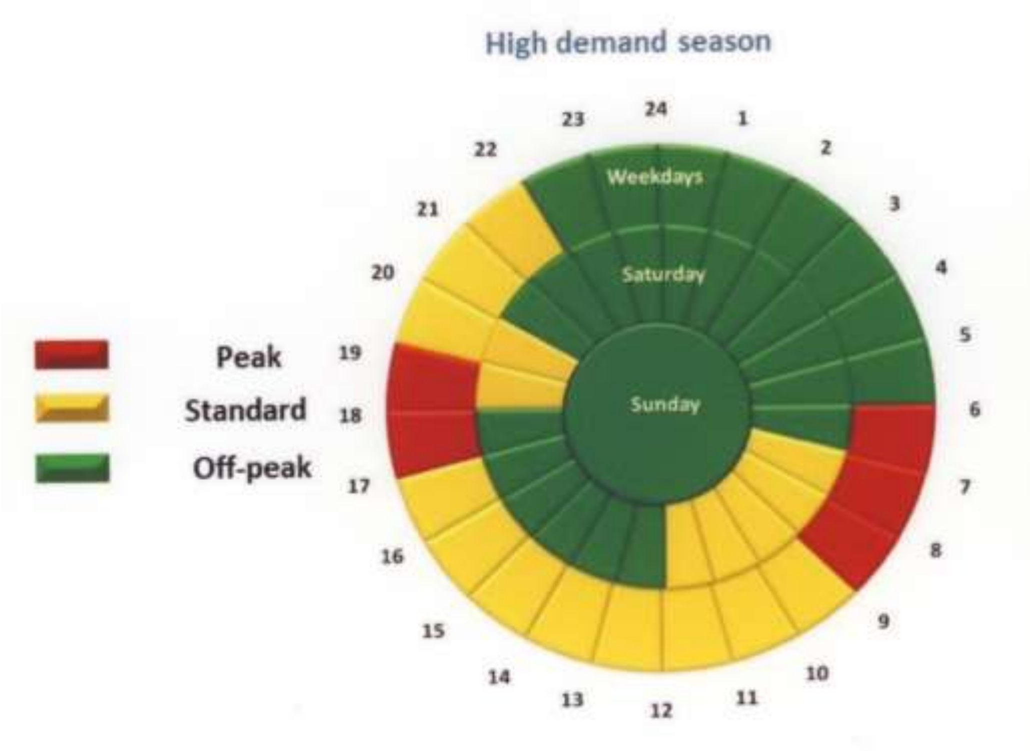

Figure 50 – TIME BLOCKS IN HIGH DEMAND SEASON.

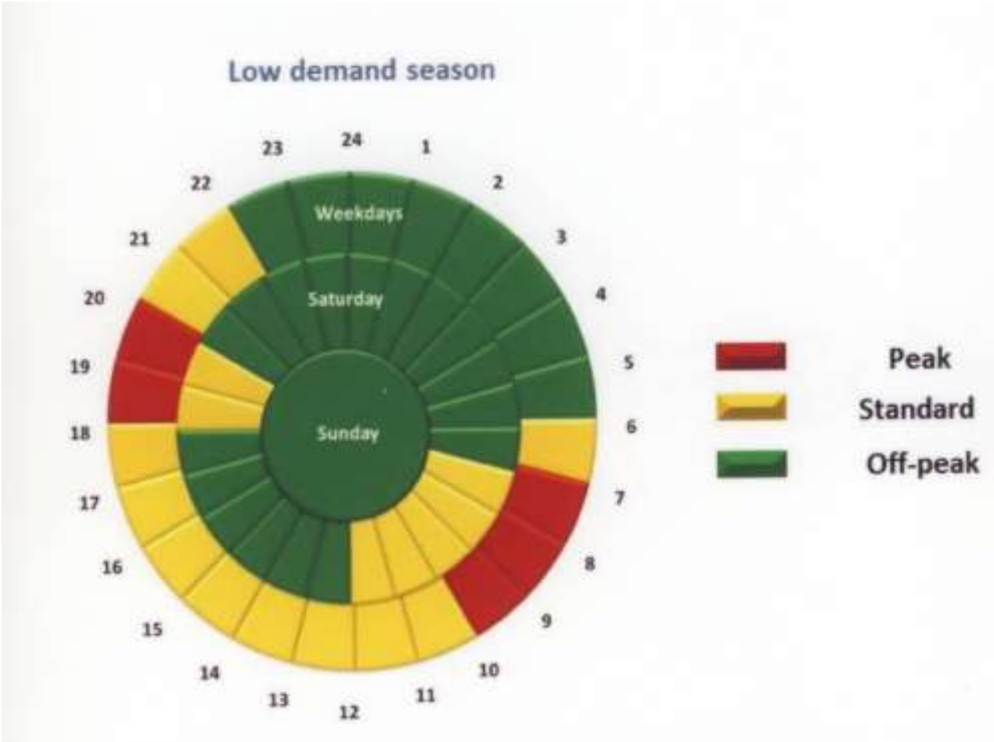

Figure 51 – TIME BLOCKS IN LOW DEMAND SEASON.

The Table 6 below shows hon the Peak, Standard and off-peak rates compare. For example, in the high demand season, the peak rate is 3.30 times as much as the standard rate.

TABLE 6 – COMPARISON OF PEAK, STANDARD and OFF-PEAK RATES FOR HIGH DEMAND AND LOW DEMAND SEASONS.

	HIGH DEMAND SEASON	LOW DEMAND SEASON
TARIFF TYPE	COST RELATIVE TO STANDARD	COST RELATIVE TO STANDARD
PEAK	3.30	1.45
STANDARD	1.00	1.00
OFF-PEAK	0.54	0.63

There will generally be three kWh meters – one for each period.

5.7 MINIMISING PEAK PERIOD ELECTRICITY USAGE.

As seen in Table 6, there is a very large difference in the cost of electricity between Peak and Standard periods. There is therefore potential to minimise electricity usage during the two peak periods.

In wastewater treatment, these peak periods will probably overlap with the peak aeration requirement periods at the works. There is probably not much potential to reduce electricity usage during these periods by reducing aeration – one does not want to adversely affect effluent quality. This is where the Process Controller can play a very important part in saving electricity by looking at other parts of the treatment process such as sludge handling. Is it possible to reduce or even temporarily halt certain processes during these periods?

Even if the electricity supply is not of the Time of Use type, any reduction in electricity usage during these periods will assist the electricity supply authority.

In water treatment, it might be possible to reduce electricity usage during these periods by reducing pumping to distribution reservoirs. A further saving would be made by maximising pumping during the off-peak period.

5.8 LOAD FACTOR.

The load factor is defined as the average load divided by the peak load in a specified time period – typically 1 month. It is a measure of the utilization rate, or efficiency of electrical energy usage; a high load factor indicates that load is using the electric system more efficiently.

For example:

1. Maximum Demand = 500 kVA;

2. Electricity Usage = 150 000 kWh;

3. Days in billing cycle = 30.

$$\text{LOAD FACTOR} = \frac{\text{Electricity Usage for the 30 days x 100}}{\text{Max Demand x 24 h/d x 30 d}}$$

$$= \frac{150\ 000 \times 100}{500 \times 24 \times 30}$$

$$= \frac{150\ 000 \times 100}{360\ 000}$$

$$= 41.7\ \%$$

If the **load factor** ratio is above 0.75 the **electrical** usage is reasonably efficient. If the **load factor** is below 0.5, there are periods of very high usage (demand) and a low utilization rate.

In wastewater treatment with relatively high peak loading rates, it will not be possible to get a good load factor. One cannot compare the load factor of one wastewater treatment works with another as there are so many variables. All one can try to do, is to improve the load factor on one's own works.

CONCLUSION.

All the matters detailed in this part are subject to the Process Controller or the Works Manager having access to the electricity meter readings and the electricity account, in order to see where the process may be optimised. This is unfortunately not always the case.

This is the end of volume 5 and it is hoped that Process Controllers have gained useful knowledge into electricity.

A final note –

ELECTRICITY IS DANGEROUS AND CAN KILL – SO BE SAFE WHEN WORKING WITH ELECTRICAL EQUIPMENT.

P B KIng 2020