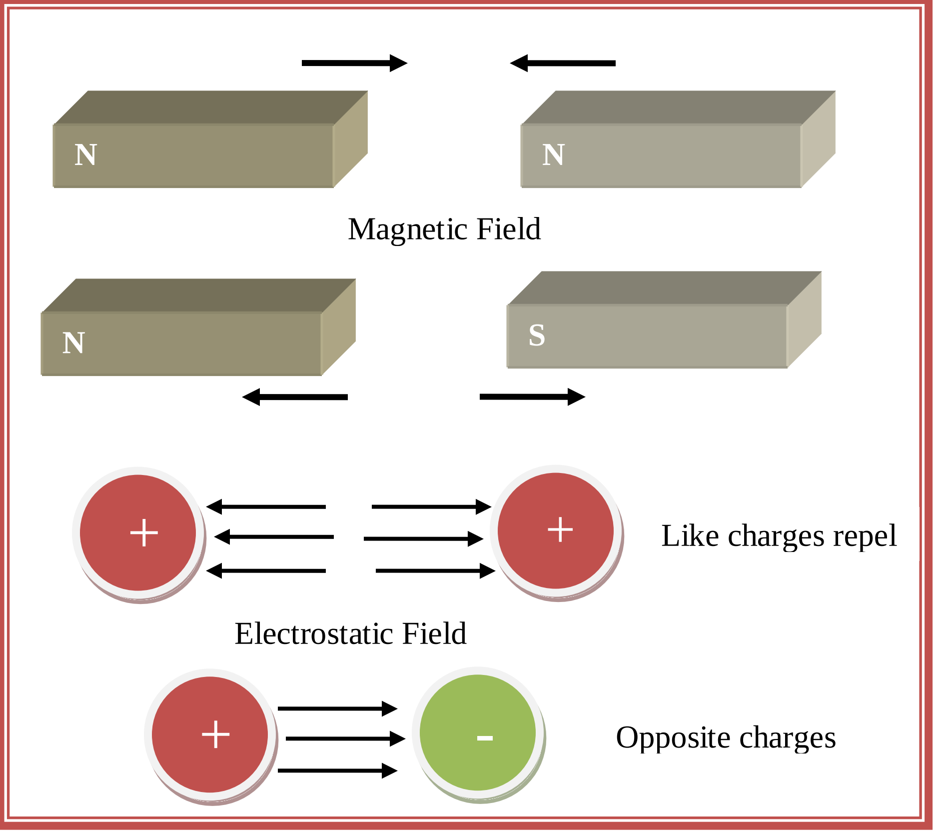
NEWSLETTER FOR MANUFACTURING COMMUNITY

Maintenance Circle

Word for the day: **CAPACITORS**

It would be pretty hard to imagine wonderful rain on a relaxed night without someone in the sky taking our "pictures", that too using bright flash light!! Well, after years of throwing light on this "light" thing, some intelligent scientists – including well known Benjamin Franklin – gave it a name, "lightning" and described it this way: When two clouds accumulated with "positive" & "negative" charges come close to each other, the "electrons" jump at very high speed and generate extremely high "electrostatic voltage." This high intensity of voltage ionizes surrounding air, which finally ends in "thunder." Same scientists are of opinion that if such high voltage can be somehow "captured" and "stored," it could end power problems for years. But as it stands today, we are too far from seeing this dream being realized.

And, somewhere sometime in our early life, we must have enjoyed either raising hairs on our (or other's) hand or lifting few bits of paper using a comb, just after repeated combing.



What can these two entirely different examples have in common? Both these demonstrate one of the oldest known type of storing energy: *By using electrostatic field*. We know that in a magnetic field, the like poles repel and unlike poles attract towards each other. Similarly in an electrostatic field, there are positive & negative charges, which attract and repel based on their polarity. The electrostatic field is generated using two separate metal conductors for storing positive and negative charges. When these two "charged" plates are bought near to each other, they exchange electrons and discharge the complete energy (the energy will be dissipated usually as heat).

Now, by adding a non-conducting material – generally called insulator – between two "charged" plates, the discharge can be prevented. Since this material prevents "two" charges from exchanging energy, it is called "dielectric" material. A combination of two conductors and one dielectric form the basis of one of the most fundamental components in electrical and electronic system, called "capacitor," about which we will learn a little bit, more from practical view in this newsletter. Note: Explaining the most microscopic details of this "charge flow" process is beyond the scope of this newsletter, as it requires great scientific understanding and has a danger of putting our beloved readers into sleep!!

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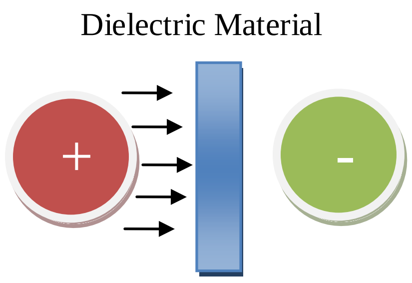

$$C\ (farads) = \frac{Q\ (coulombs)}{\quad}$$

Example: If C = 1 Micro Farad
and V = 415 Volts
then, Q = C x V = 1 x 415 = 415 Coulombs

The amount of charge stored in a capacitor is measured as capacitance and usually represented by unit, "farad." A one farad capacitor stores one coulomb of electrostatic charge when a potential of one volt is applied across its terminals. Farad represents very large capacitance and for practical purposes, its lower units are used:

1. One Microfarad (1 μF) = 1 x 10^{-6} Farads
2. One Pico farad (1 pF) = 1 x 10^{-12} Farads

As you can see from the formula above, the capacitance required reduces as the voltage increases. In a typical electrical distribution for example, the capacitor will be smaller if installed on 415V side instead of say 230V side.

The amount of charge stored by a capacitor is directly dependent on two major factors: Area of conductor and the distance between conductor plates. Larger the conductor area, larger will be storage capacity. Similarly, closer the conductor plates, which also mean a thin dielectric material, larger will be storage capacity.

Tip for the newsletter

Capacitor can be imagined as equivalent to a sponge block holding water. The quantity of water absorbed & held by sponge depends on two factors: (i) Volume of sponge (ii) The porosity – distance between micro holes – of sponge material. Larger the volume (compare to higher conductor area), higher the water storage capacity. Lesser the porosity (compare to less dielectric thickness), higher the water storage capacity.

Thin Steel, Aluminum, Copper, Titanium and other superior metals are generally used as conductors.

Type of dielectric material used also defines amount of charge stored in a capacitor and is usually represented by "Dielectric constant." Material with high dielectric constant will store more charge than the material with lower value. Some of the dielectric materials used and their dielectric constants are shown in the table-I.

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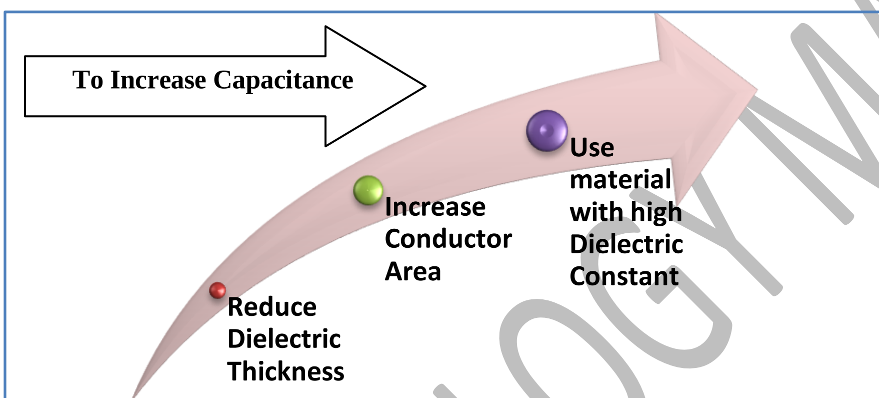
Table I

Material	Constant
Vacuum	1.0000
Air	1.0006
Paraffin paper	3.5
Glass	5 to 10
Mica	3 to 6
Rubber	2.5 to 35
Wood	2.5 to 8
Glycerin (15°C)	56
Petroleum	2
Pure Water	81

As you can see from the table, vacuum or air is the standard reference dielectric medium. Pure water has highest dielectric constant. Paraffin paper, glass, mica are the most commonly used dielectric materials due to easier manufacturability into thin shapes, longer life, stability and optimum cost factor.

Taking the dielectric constant into consideration, we can re-write the formula for calculating capacitance as follows:

$(C = 0.2249 \text{ x} \frac{K \, x \, A}{d})$, where **C** = Capacitance in Pico farads, **K** = dielectric constant, **A** = Area of the conductor in square inches and **d** = distance between conductor plate (indirectly, dielectric thickness) in inches.



So, capacitance of a capacitor increases in direct proportion to dielectric constant and conductor area and in inverse proportion to distance between conductors or dielectric thickness. Also, higher dielectric constant indicates its ability to hold charge for longer duration.

From the preceding explanations and formula, it is evident that the dielectric material should be as thin as possible to retain more charge and increase capacitance at the same time. Of course, the conductor area can also be increased to get same capacitance. But this will increase the size and cost of the capacitor. An optimum balance between the capacitor dimensions and type of dielectric material used will be decided based on end application.

Dielectric material and its properties play a vital role in deciding the life and quality of capacitors. The ability of dielectric material to withstand and retain voltage is called its dielectric strength. The dielectric material and its thickness decide the dielectric strength. For same material, dielectric strength will increase if thickness is increased.

If the applied voltage exceeds specified limit, dielectric material will rupture and cause a short between positive and negative plates, eventually damaging the capacitor. To prevent capacitor failure due to surge voltages during switching cycles, 50% safety factor must be taken into consideration. For example, if a capacitor is required to be fitted in a 415V AC circuit, its dielectric strength should be approximately equal to 1.5 times 415V, which is 622.5V AC. Based on the application, a capacitor can have mica, paraffin paper, plastic or air as dielectric material. Following points must be taken into consideration while selecting a capacitor with specific dielectric material.

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- Application type – power factor control, surge elimination etc.
- Type of voltage – AC or DC
- Magnitude of voltage expected across capacitor
- Voltage frequency
- Charging & discharging cycle
- Surrounding conditions
- Space constraints

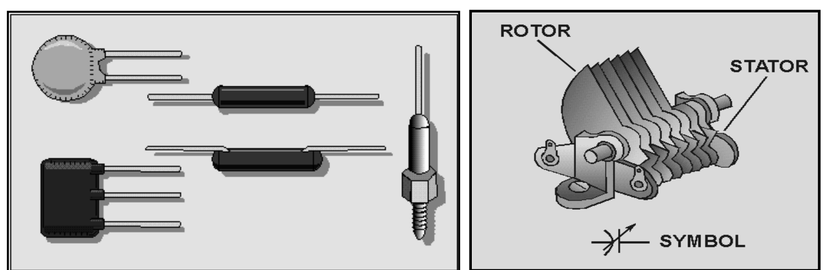
Theoretically, dielectric material is a pure insulator with very high resistance and is expected to retain capacitor charge for infinite period. But in practical conditions, dielectric material also has some conductivity and hence a capacitor when left disconnected for long time will slowly discharge the stored voltage. Any internal damage or failure or rupture of dielectric material accelerates this discharge.

> When a new capacitor is installed, measure the voltage across its terminals and record the value. Repeat the measurement every month to indirectly diagnose the condition of dielectric material. A rapid reduction in voltage indicates dielectric failure.

The dielectric material is broadly classified into two groups: Non-healing (NH or NSH) & Self-healing (SH) type. Non-healing type dielectric materials completely short the capacitor if any damage occurs due to high voltage or overloading and has to be replaced immediately. This is somewhat similar to a fuse which blows due to over current and needs immediate replacement. Most of capacitors used in electronic circuits, motor starters are of non-healing type. Self-healing type dielectric materials do NOT completely short the capacitor when damaged. The area of dielectric material where damage has occurred closes itself. This means, the storage capacity of capacitor gradually reduces until the entire dielectric material is damaged. Self-healing type is typically used in drives, power factor control systems, and large capacitor banks.

Capacitors are available in two categories: Fixed and Variable. As the name implies, capacitance value of a fixed capacitor remains constant throughout its life. Majority of capacitors that we use are of fixed type. On the other hand, the capacitance of a variable capacitor can be adjusted over a range. One of the most classic example is old tuner radio in which the stations were changed by varying the capacitance. Variable capacitors are widely used on modern televisions, communication equipments.

Based on the value of capacitance required, we can connect more than one capacitor in series or parallel connection. In parallel connection, the total capacitance is INCREASED and in series connection, the total capacitance is REDUCED. A combination of parallel and series connections can also be made to obtain required capacitance value.



FIXED VARIABLE

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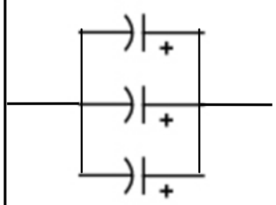

In Parallel

$$C\ total = C1 + C2 + C3$$

Example-1:

C1 = 3µF C2 = 2.5µF C3 = 4µF

In parallel connection,

C total = 3 + 2.5 + 4 = 9.5µF

In series connection,

$$\frac{1}{Ctotal} = \frac{1}{3} + \frac{1}{2.5} + \frac{1}{4},$$

C total = 1.017µF

In Series

$$\frac{1}{Ctotal} = \frac{1}{C1} + \frac{1}{C2} + \frac{1}{C3}$$

By now, we are quite aware that the capacitor stores and discharges energy. The storing of energy is accomplished by connecting capacitor to an external voltage source, AC or DC. On the other hand, by connecting the capacitor to a load, it can be discharged. The "time" required to charge or discharge a capacitor is determined by capacitance value, charging voltage and discharging load. Therefore, *the time required to charge a capacitor to 63.2% of its full charge or to discharge 36.8% of its full charge is called* ***TIME CONSTANT***.

The value of time constant is generally equal to multiplied product of total resistance (load) in circuit and capacitance value. It is represented by equation, t = RC. Some of the other variants of this equation are shown in the table below.

t (seconds) = R (in Ohms) x C (in Farads)
t (seconds) = R (in Mega Ohms) x C (in Micro Farads)
t (micro seconds) = R (in Ohms) x C (Micro Farads)
t (milli seconds) = R (in Mega Ohms) x C (Pico Farads)

Let us calculate how much time it takes for a one micro farad capacitor to be discharged, when connected to a 6 mega ohm resistor (refer second formula in table).

t (seconds) = 6 x 1 = 6 seconds.

Apart from the resistors, there could be inductors and other components in the circuit. Explaining how these influences the overall time constant of a capacitor is little beyond the scope of this newsletter. But this simple equation can be useful for day to day applications.

Although capacitors are used in many areas, two of the most widely used applications which we will be discussing in next week's newsletter are: POWER FACTOR CORRECTION & MOTOR STARTING SYSTEM.

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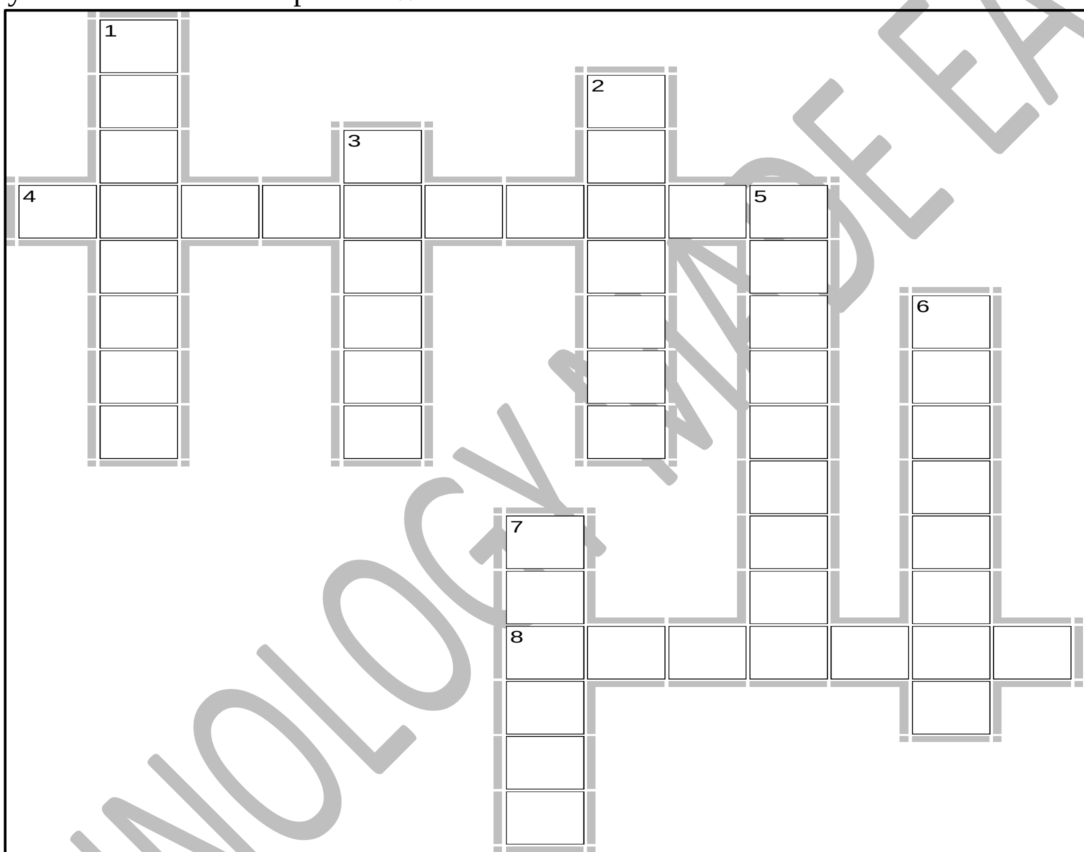
Power factor correction is one of the most critical areas of an electrical distribution system. Controlling power factor not only avoids PF penalty, but also increases the life of all electrical equipments, including transmission cables. We will be going thru the entire process of studying, selecting and designing a power factor control system. And, not to forget the maintenance aspect of the system on which we will throw some light as well.

Don't go away. Wait to read and appreciate these and many more interesting aspects from the world of capacitors!!

For now, enjoy this Techuzzle on capacitors!!



Across

4. Thinner I get, higher is my capacity
8. Capacitor stores energy using this

Down

1. Type of capacitor on old radios
2. One of the common dielectric materials
3. Connect capacitors like this to reduce total value
5. Bigger I get, higher my capacity is
6. Connect capacitors like this to increase capacity!!
7. Dielectric constant is one