*Polytech'Orléans*

**p o l y t e c h n i q u e**

***Institut***

***de l’université d’Orléans***

# Master AESM

Aesm2

Electrical Power

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**1/ Single phase linear power load:**

**Convention : receiver**

i(t)

 🔾

Instantaneous power: **p(t) = u(t) . i(t)**

mean power: **P = < p(t) > = [ W ]**

 u(t)

 🔾

**Steady state sine :**

Instantaneous variables instantaneous complex instantaneous complex magnitude

u(t) = U cosωt u(t) = U ejωt  U = U

i(t) = I cos(ωt - ϕ) i(t) = I ej(ωt-ϕ) I = I e-jϕ

This is the active power, denoted **P**

**P = < p(t) > = **

**UIcosϕ**

 **=**

**Apparent Power : S = U . I**  in **VA**

The Root Mean Square voltage value (U) is used to calculate the dimensions and the properties of materials for the insulators:

 e.g. low voltage :

 240 v , 400 v , 660v

 e.g. high voltage :

 20kV (case of Polytech Vinci )

The Root Mean Square current value (I) is used to calculate the dimensions and the properties of materials for the wire used in lines and power grids usual current density 8 A/mm2

**Power factor : F**

It is defined as the ratio of the maximum active power **P** (**watt)** over the apparent power **S** (**VA** ), which gives the dimensions and hence the cost

 

**Apparent complex power :**

 **S = U . I\* = U . I ( cosϕ + j. sinϕ ) = P + j . Q**

A new variable, the imaginary part of **S** denoted **Q**, appears here. It is called

**Reactive power**

The meaning of this new variable is not easy to understand.

It means that the current has a different phase from the voltage.

It is not in phase with the voltage

Let us take two examples:

If the current is in phase with the voltage φ defined above, equals zero so sine (φ) also equals zero.

So Q equals zero

If the phase of the current is π/4, **Q** is expressed as $UI\sqrt{2}$ /2 exactly the same as **P.** So the **magnitude** of theapparent power **S** becomes UI greater than the active power.

$$S=\sqrt{P^{2}+Q^{2}}=UI\sqrt{(\frac{\sqrt{2}}{2})^{2}+(\frac{\sqrt{2}}{2})^{2}^{}=}UI\sqrt{\frac{1}{2}+\frac{1}{2}}=UI$$

In fact the presence of that term increases **S** with a constant **P** or decreases **P** with a constant **S**. Overall it decreases **F**. The cost is given by **S** so a system with a low power factor is more expensive than a system with a higher power factor.

It is therefore one of the engineer’s jobs to maximize the power factor by reducing or cancelling the reactive power.

**2/ Single phase non linear power loads;**

**💣 Case of non linear loads:**

The electrical grid is always a sine voltage source.

The current however is not always sine.

A special kind of receiver is a non linear receiver. This means that the ratio between voltage and current is not as simple as:

U=Z.I

1/ This means that the impedance does not exist.

2/ The load distorts the shape of the current which will not be a sine.

3/ It is not possible to define a phase and therefore a reactive powere.g. diode bridge GRAETZ, used in stabilized supply.

This is the system employed in AC:DC converters ordinarily used in electronic systems to transform the sine voltage from the grid into a direct voltage . A transformer decreases the voltage and a diode bridge rectifies it with the help of a capacitor.

Let us consider the current denoted **iS** on the grid shape is not a sine but remains periodic, with the same period as the grid : 20 ms.





One way to describe this current with a mathematical formula is given by the Fourier series.

So: **i(t) = <i(t)> + **

****

n= ?

n=

n=3

n=1

This figure represents the magnitude spectrum of all the components of the current.so the active power is:

**P = <u.i> = **

Let us consider three possibilities to calculate the integral easily.

**n=0**  =

  **0**

**= 1  = cosϕ1. T/2**

**n >1  =  =**

 **0**

**P =P=UI1cosφ1**

**💣 Active power is carried only in the fundamental term (n=1) of the current**

-This property appears because the voltage is a sine

-The harmonic terms of the current create only joule losses and increase the heat dissipation in the wires. This is an undesirable effect because it damages efficiency.

The international standard **IEC 1000-3-2** describes the maximum thresholds for harmonic currents in domestic or industrial systems .

**Power factor :**

**F = **

In so far as I1 is always less than I, so F is degraded by the presence of harmonic currents.

**Root mean square current:**

I =  =  = 

because only the same pulse products contribute to this amount

**Apparent power application: S=UI**

case of null mean current: <i> = 0

 hence **i(t) = **

**S = UI = U  =  =  = **

**S1 = ** (this formula can be applied to this linear regime)

**P1** is the active power carried by the fundamental current, the only useful term for the transmission of energy; unit of measurement: Watt. In fact **P** is restricted to **P1**.

**Q1** is reactive power in this circuit, definable as the current concerned is fundamental, so sinusoidal. Unit VAR

**D** is called the distorting power. It reflects the fact that there are harmonics on the current, so that its appearance is distorted from the pure sine wave. Unit VAD

**3/** **Power measurement P using electrodynamic power meter needle:**

**i(t)**

Intensity circuit (large gauge)

\*

**W**

Voltage measurement circuit (narrow gauge)

\*

**Z**

**u(t)**

**W = < u.i >**

**in Watt**

**V**

**A**

The meter measures the product in 2 sizes: the voltage **U** and the current **I**. When one of the sizes is low, the other may exceed its rating, i.e. its measurement range, thereby permanently damaging the power meter. To guard against this situation one should always use both a voltmeter and an ammeter when measuring power. The sizes of measuring circuits are always expressed in effective values as it is consistent to adopt the RMS of ferromagnetic nature for A devices and V.

**4/ What is three phase?**

It is one of the best ways to carry electrical energy for industrial needs

 (N.Tesla 1887-1888).

Consider three sine voltages with the same magnitude $\hat{V}$ , the same pulsatance ω but with different phases.

We can see on the figure that the time delay is T/3 or 2π/3 in phase.

This is a balanced three-phase voltage system.



The smaller voltages are called simple voltages.

The larger voltages are called compound voltages.

**Mathematical formula:**

**Simple voltages**

**** this system is called **direct**

**** this system is called **undirect**

**Compound voltages**

****

**For example u12**

****

One can demonstrate that compound voltages constitute another balanced three-phase system with a magnitude of $\sqrt{3 }\hat{V}$

**Complex notations**

****

**Fresnel figure**













U12

**Trace the next compound voltages**

**5 Star coupling for sources and loads : YY**

**I1**

**N**

**N’**

**Z**

**Z**

**Z**

**E1**

**E2**

**E3**

**IN**

**I2**

**Neutral**

**Neutral**

**VNN’=0**

**I3**

The sources are a system of balanced three-phase quantities.

 The three loads are balanced. Each load value equals **Z**

**I1  = **

**I2 =  =** a **I1 ⇒ IN  = I1 [ 1 + a + a2 ] = 0**

**I3 =  =** a2 **I1**

**6 Star coupling sources delta coupling loads : Yd**

**J31**

**I1**

**E1**

**J12**

**Z**

**Z**

**E2**

**E3**

**J23**

**Z**

**I3**

**I2**

**I1  = J12 - J31 I :** RMS value of the current line

**I2 = J23 - J12 J :** RMS value of currents in the phases of the load

**I3  = J31 - J23  **as compound values

**J12  = **

**J23 =  =** a **J12 ⇒** $\sum\_{}^{}J\_{n}$ **= J12 [ 1 + a + a2 ] = 0**

**J31 =  =** a2 **J12**

All the currents form a balanced three phase system.

Themaindifferencebetweenthetwocouplingsisthe voltage value on each load.

**YY** in this way it equals V

**Yd** in this way it equals $\sqrt{3}$V

With the same source grid

Exercises

Calculate the RMS of E to obtain 660v on Z in the delta mode.

Choose the coupling to obtain 237 volts upon Z with E equaling 237V?

**7 The three-phase power in three-phase distribution of balanced voltage on any network:**

 The total power W is the sum of the separately measured powers



This shows that the total power is independent of the potential

of the point N’.

It can therefore be used freely. By writing N’= T,

W3 can be cancelled and this wattmeter therefore deleted.

This makes it possible to simplify the connections.

**8 Case of three phase balanced linear loads :**

**P = <u13 .i1> + <u23.i2>**

 **= U.I [ cos(θ13) + cos(θ23) ]**

**Angle definition :**

 **θ13  = -π/6 + ϕ**

 **θ23 = π/6 + ϕ**

**P = U.I.(cos(ϕ-π/6) + cos(ϕ+π/6))**

 ****

**Π/6**

**Π/6**

**ϕ**

**I1**

**I3**

**I2**

**θ23**

**U23**

**θ23**

**U13**

**θ13**

**ϕ**



**Measurement of P and Q on measurement of P on a load-balanced star coupling**

****

**Measure P on unbalanced load: 2 Wattmeter’s method**

 What about the reactive power ?

 In the case of the linear well balanced load

 S=3VI=$√3UI$=$\sqrt{3 }UI\sqrt{\left(cosφ^{2}+sinφ^{2}\right)}=\sqrt{P^{2}+Q^{2}}$

 Therefore it defines the reactive power in three phase system as: Q = $3VIsinφ$