Green Power Solutions

Plastic Film Capacitors: be active in choosing the passive!

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1. Focus on the ratings and specifications

- What to know about the main variables, electrical characteristics and the related operative critical issues

Voltage

- Rated Voltage Ur is
  - the maximum direct voltage
  - or the maximum rms voltage
  - or the peak value of pulse voltage

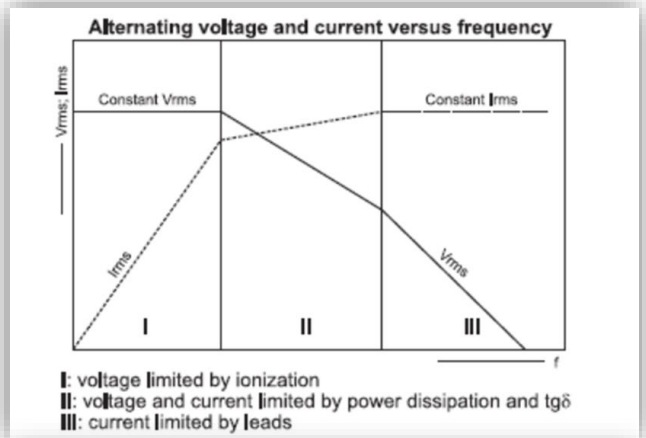
which can be continuously applied within a given operative (case) temperature range

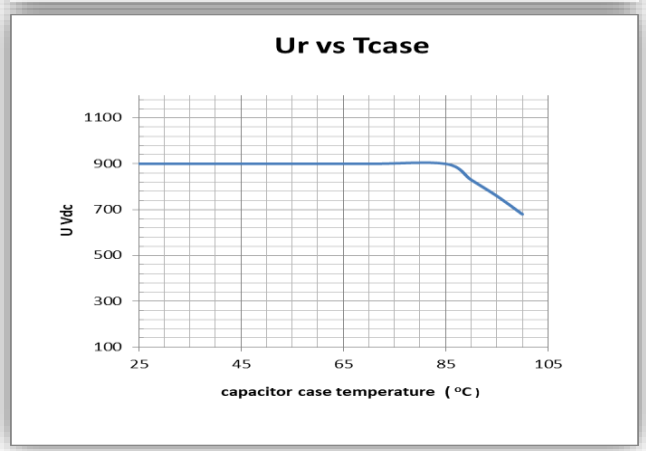
- When AC voltage is permitted and present in the application, sum of Vdc and peak Vac must not exceed Ur

- Even if permissible AC voltages would cover lines voltages, ICEL S.r.l. capacitors for power applications are not suitable for across the line applications (X-Y class)

Voltage

- Max admissible dissipated power must always be considered according to working frequency and temperature
- Permissible AC voltage can be obtained from AC voltage versus frequency graphs
- At high temperatures voltage derating must be applied





Voltage

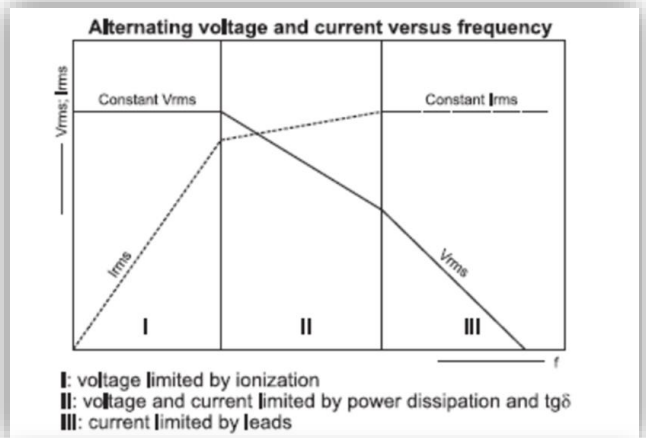
- Using higher than rated voltages may cause ionization (corona effect) and permanent damages
  - dielectric perforation
  - capacitance drop
  - insulation resistance decrease
  - short circuit

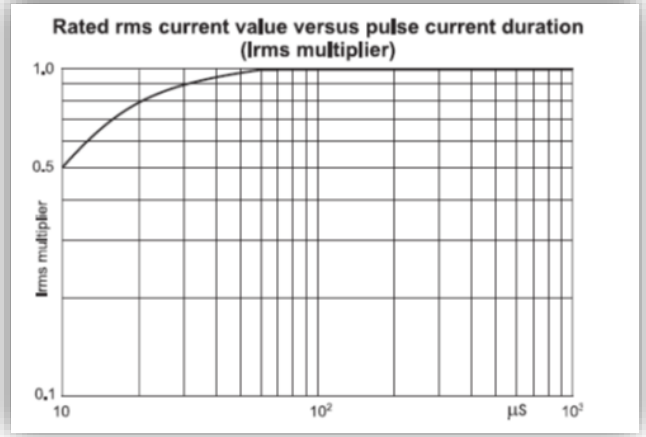
→ lower reliability = shorter expected life + higher failure rate (we will see later)

- Grade of damage depends on different factors
  - trapped air
  - type of dielectric and electrodes
  - design and construction
  - accuracy of manufacturing process
  - working conditions

Current

- Rated rms Current Irms is
  - The highest permissible rms value of the continuous current flowing through capacitor at specified max. Ttot
- Max. Irms is given at certain frequency – typically 10kHz or 100kHz
- Power dissipation and related current derating must be considered according to operating frequency
- In pulse applications with short pulse duration, also skin effect in contacts should be taken in account

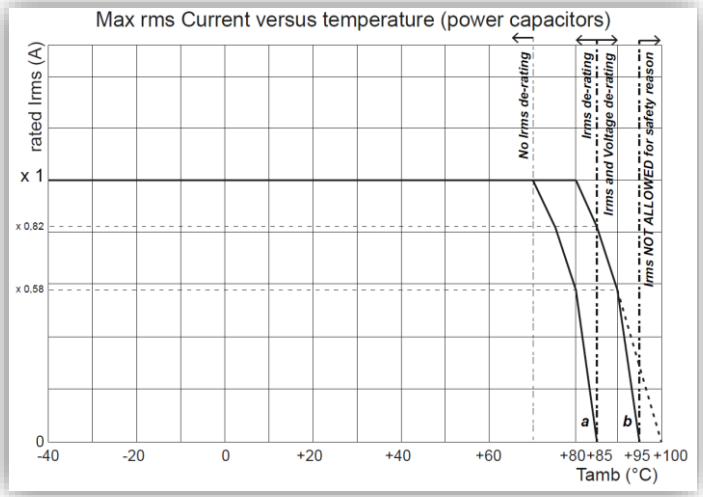




Current

- Main effect of current flowing through capacitor is heating*
  - $T_{tot} = T_{amb} + \Delta T$ must remain lower than the specified max operating temperature
  - to keep the T_{tot} under control derating can be required depending on the operating conditions

- Peak current flowing through capacitor causes localized heating on contact areas due to contact resistance between leads and capacitor element



Curve a: DCH, DCS, PHC, RHB, RMC, PPS, PPA, RSB, RMB, MAR
Curve b: other series for power applications

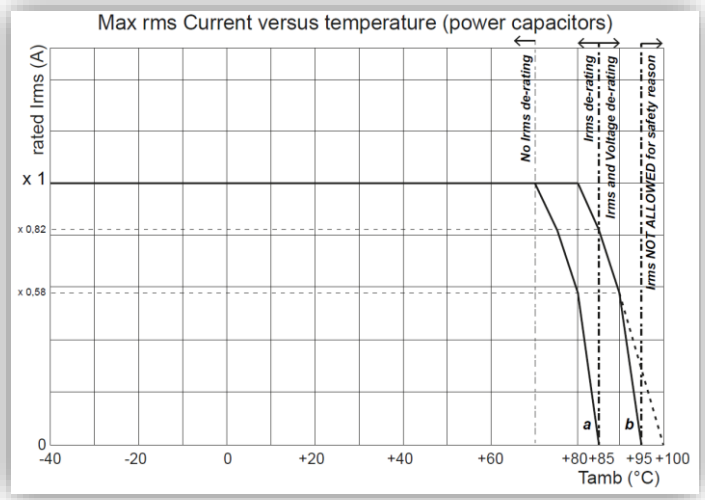
*Power loss – Joule effect due to "Equivalent Series Resistance" (ESR) of a real (non-ideal) capacitor. It is related to the "Dissipation Factor" (DF or tgδ). See backup slides

Current

- Heating extends to entire capacitor body, when pulse stress is repetitive
  - combined effect of pulse and rms currents must be considered and maximum Ipeak and Irms values not to be exceeded

- It is necessary to guarantee the correct dissipation with a good mounting layout, avoiding direct contact of the components or too close positioning (see backup slides)

- Excessive heating can cause deterioration up to short or open circuit, body deformation and melting with smoke emission and fire



Curve a: DCH, DCS, PHC, RHB, RMC, PPS, PPA, RSB, RMB, MAR
Curve b: other series for power applications

lower reliability = shorter expected life + higher failure rate (we will see later)

Temperature

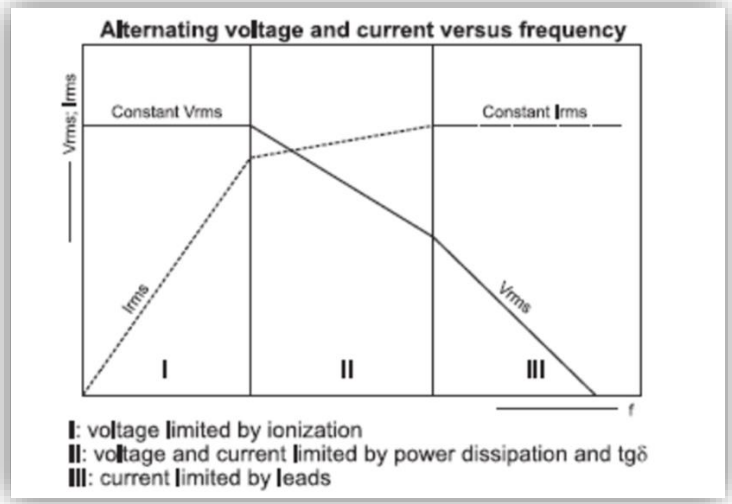
- Rated temperature is the maximum temperature (Ttot) at which the rated voltage may be continuously applied

- Working at high operating temperatures Ttot may require voltage and current derating
  - Typical voltage derating for power capacitor
    - Ur decrease 1,5% for every °C exceeding +85°C
    - Urms decrease 2,5% for every °C exceeding +85°C
  - Irms is typically derated in relation to Tamb

- Ttot is measured at the hottest point
  - typically near the contacts/heads or on areas having poor dissipation capability because of external reasons like presence of other hot components or heating sources

Frequency

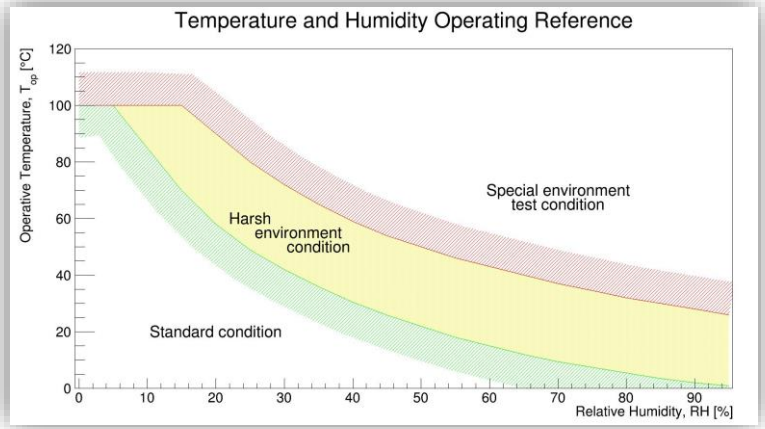
- The maximum power dissipation admitted under normal conditions depends on many different factors
  - Execution, design, shape, dimensions, materials
- voltage and current derating must always be considered, in order not to exceed capacitors max. dissipated power and to avoid overheating
- At high frequencies (III) changes in dissipation factor and ESR will increase the heating of the capacitor and also current derating can be required to control the total power



Humidity

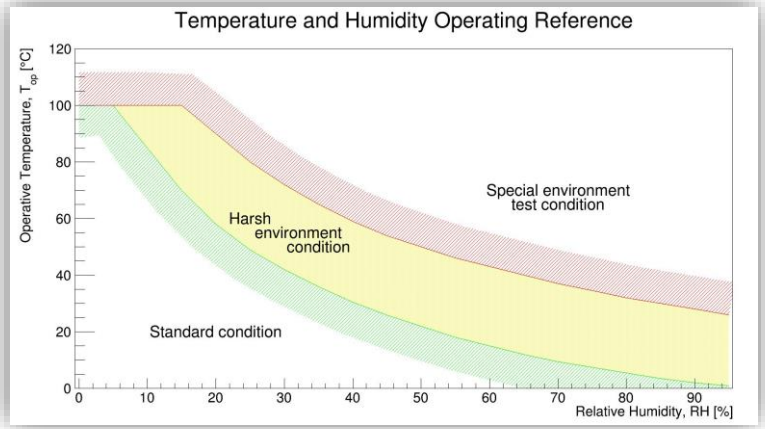
- Capacitor used in **moist ambient** absorb humidity
  - this can cause **gradual electrodes oxidation** and in medium or long term **capacitor damage or failure**

- Capacitor eventually **modifies characteristics** according to **environmental conditions**
  - magnitude and speed of modifications depend on dielectric, design and protecting materials
  - with **special design** and insulation materials **the speed of this process can be slowed**



Humidity

- The combination of high operation temperature and high humidity (especially in AC operation) is a particularly dangerous condition, potentially causing a fast ageing of the capacitor with related relevant decrease of expected life and increase of failure probability
  - humidity can cause electrochemical corrosion destroying the metallization and causing capacitance and insulation resistance drop, overheating, swelling of the capacitors and potentially ending up to short circuit and fire



2. Reliability

- Definitions – what is meant for “reliability”
- How to read and understand specifications, comparing data of different manufacturers
- Prescriptions, precautions and useful suggestions to maximize the reliability

Reliability

- The reference reliability states a component type fraction failure under a defined load or operating condition
  - this fraction failure theoretically will not be exceeded within a specified operating time

- The reference operating condition for ICEL S.r.l. power capacitors to which the reliability is referred, are the maximum ratings (rated voltage and rated temperature, without de-ratings applied and no humidity considered), unless differently specified at types specifications
  - some competitors use as standard reference conditions 0,5xUr(DC) at +40°C

Failure Rate

- The Failure Rate is expressed in FIT (failure in time)
  - 1 FIT= 1 x 10^{-9} / h (1 failure per 10^{9} component hours)

- The Failure Rate, when available, is referred to failure rate criteria like short or open circuit, main electrical parameters variation above declared limits at each type specification and so on

- Conversion factor CF can be used to estimate expected failure rate in different conditions

Working Voltage (Uw/Ur)	CF
1	x 20
0,75	x 4
0,5	x 1
0,25	x 0,4
0,1	x 0,2

Working Temperature(°C)	CF
≤ +40	x 1
+55	x 2,5
+70	x 6
+85	x 15
(+ 100)	(x 45)

Lifetime Expectancy

- Also the **Lifetime Expectancy** is typically referred to the **rated voltage Ur** and to the **hot spot temperature** of the capacitor case Ttot (the typical reference temperature is stated at type specifications)

- Life Expectancy can be expressed as **a function of operating voltage and temperature**
  - The obtained estimations are based just on voltage and temperature parameters, **NOT considering any other possible stress source**, for example **humidity level**
  - Whichever is the obtained estimation, **orders of magnitude higher than the reference** value **do not represent realistic data: keep a rational approach interpreting the result**

$$L_w = L_E \times (U_r/U_w)^E$$

L_w = Life expectancy at working voltage Vw
L_E = Life expectancy at nominal voltage Vr
U_r = rated voltage
U_w = Working voltage
E = value depending on capacitor design and construction, typically 8.

$$L_w = L_E \times 2\,(T - T_{hs})/Ac$$

L_w = Life expectancy at operating temperature
L_E = Life expectancy at reference temperature
T = Reference temperature
T_{hs} = Operational Hot Spot case temperature at working conditions
Ac = Arrhenius coefficient (depends on type of capacitor, typically 7)

The formulas shall not be used for estimations outside the specification rating limits

Interpret and compare data in specifications

- Data included in the specifications must be related to the proper application and operating conditions
  - Data are provided to reference conditions (temperature, voltage, frequency, etc...) and different manufacturers can make different choices regarding the adopted references: it is up to the user to normalize all the data with respect to the working conditions of his application

EXAMPLES

- Rated Voltage: always check the temperature to which it refers (can be either Tamb or Ttot)
  - In ICEL products specifications the rated voltage is referred to Ttot (case)

Interpret and compare data in specifications

- Irms: always check the frequency to which it refers and the temperature rise ΔT to which it corresponds
  - In ICEL products specifications Irms ratings are referred to max ΔT of +15°C from Tamb to Ttot (operation at rated power, current and voltage, natural cooling, +70°C ambient or +85°C observing voltage and current deratings)

- Reliability (Expected Lifetime AND Failure rate): always check the temperature and voltage to which it refers
  - some competitors use as standard reference 0,5xUr(DC) at 40°C
  - In ICEL product specifications reliability is referred to the rated voltage Ur and to the hot spot temperature of the capacitor case Ttot

ICEL's choice is to provide the data in the "worst" conditions allowed: "*it can only go better than this!*"

Keep in mind…

- To ensure high reliability and long life, power capacitors should not be operated at maximum permissible voltage and maximum operating temperature simultaneously
- The possible presence of relevant humidity levels may critically increase the global stress and accelerate the aging of the components
- Always refer to what indicated at type specification about the voltages values and waveform applicable and allowed

Keep in mind…

- Always respect voltage ratings and choose capacitors having higher Ur than the working voltage to ensure safety margins and higher reliability

- Always refer to the specifications for the max. current and max. voltage capacitor can withstand and apply derating when required

- Testing of capacitor heating ΔT and $T_{tot} = T_{amb} + \Delta T$ shall be made in conditions equivalent to the real operation conditions and by simulating the worst case working conditions

Keep in mind…

- Heat sources external to the capacitor can transmit heat through the terminals inside the capacitor. Thus the increase in total capacitor temperature may not be entirely due to current flow. This possibility shall be avoided in order not to limit the capacitor performances

- Capacitors used in power applications are typically exposed to relevant stresses level and possible failure may result in very serious consequences. For this reason, the keeping of a wide safety margin (about 25÷30%) compared to ratings is a wise and long term profitable approach

- So far we referred to the typical behavior of the single component, net the possible layout of several units connected in series/parallel, which may increase the global risk upon critical operating conditions

3. ICEL Products

- Short presentation of ICEL company and its products portfolio

Few words about ICEL

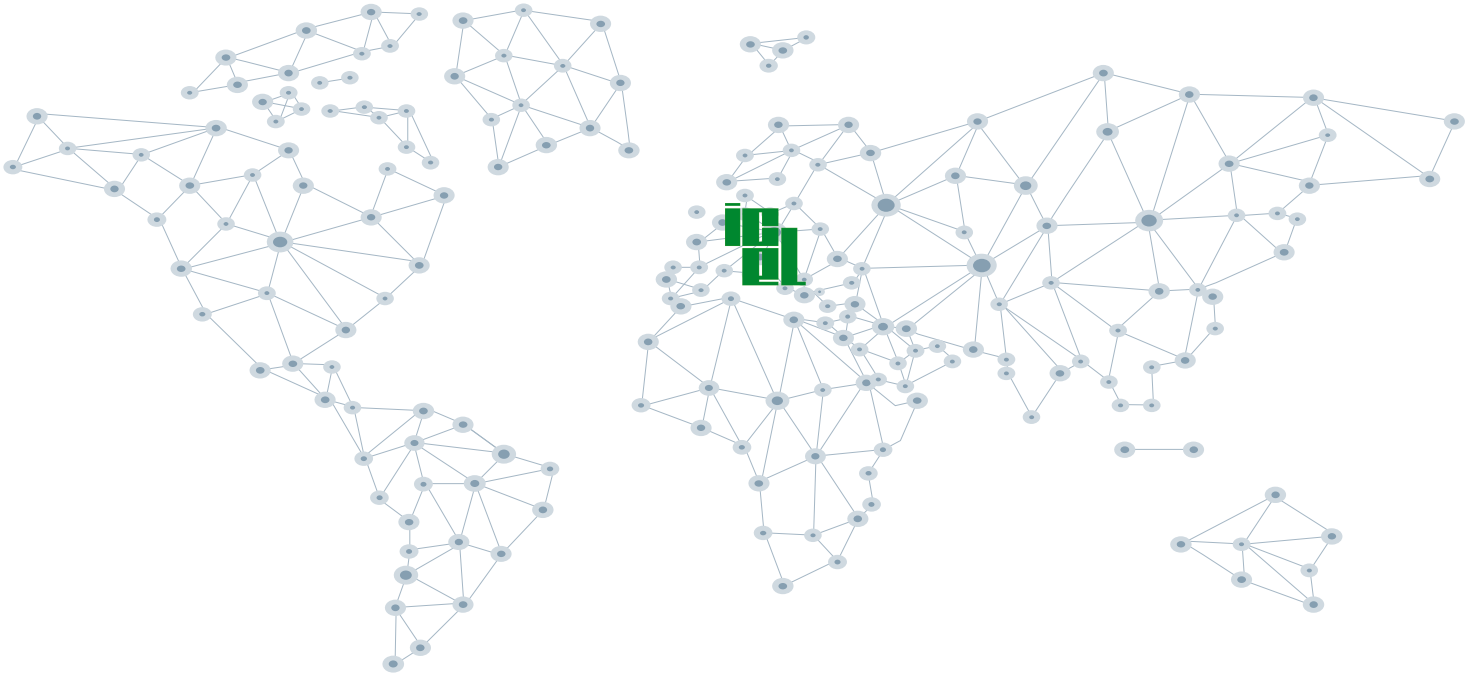
- Founded in 1960
- Family owned company
- Located in Milano area, Italy
- Design, production and distribution of capacitors
- Global presence with about 70% of production exported worldwide, mainly through distribution

Via C. Jucker 16, 21053, Castellanza (VA) - Italy

From here it all begins…

…made by the family of people who make it alive

… but there are no places we cannot reach!



https://www.icel.it/capacitor-sales-network.html

Professional film capacitors for power applications

- Polypropylene and polyester dielectric
- Axial and box executions
- Pin, lug and wire terminals

Standard and custom solutions for

- DC-Link
- AC and DC filter
- Pulse
- Snubber and clumper
- Switching
- …

Main applications and markets

Green energy (wind, solar, …)

UPS

Welding

Motor control

Lightning

Audio – high end

HV multipliers – X-ray

Power supply

Induction heating

Battery chargers

Traction

Pulsed energy (medical imaging, laser, plasma cutting)

100 reasons why – ICEL

- High automation level
- Flexible production
- Short-time deliveries
- Fast response
- Technical support
- Own film and capacitor design – custom capacitors
- Quality by knowledge, service and skills
- Certified Quality Assurance
- Recognized test laboratory
- 100% production data tracking
- 100% production tested

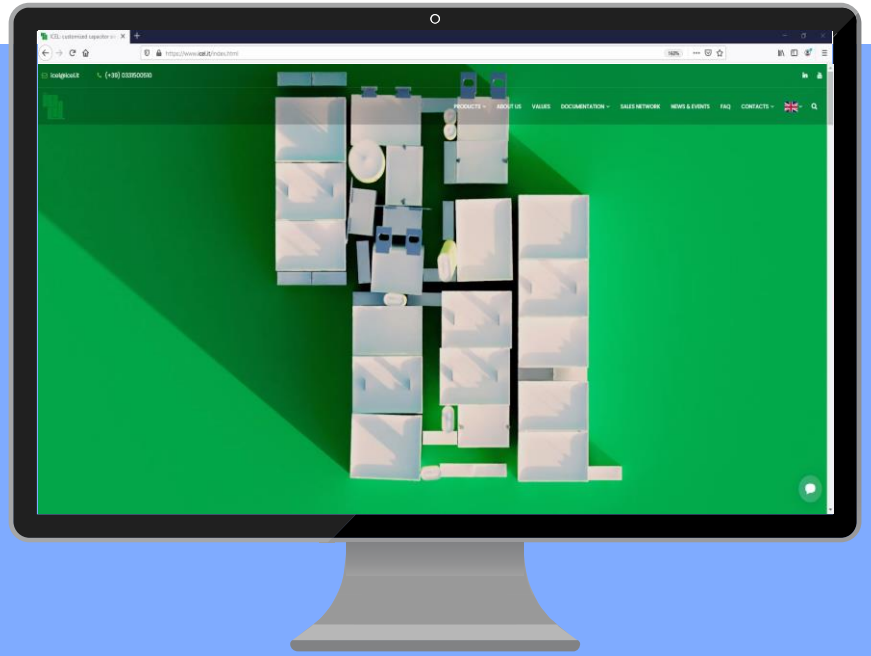
Our values

LONG HISTORY KNOW-HOW

DESIGN AND PRODUCTION OF CUSTOM CAPACITORS

FLEXIBILITY AND SERVICE

SUPPORT AND COOPERATION



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Backup slides

Current

- If nothing else indicated/permitted in data, avoid operating conditions causing relevant power dissipation at Tamb ≥+95°C (even if capacitor have higher rated upper category temperature)

- During stationary operation capacitor temperature must be always lower than max operating temperature stated for the capacitor

- Terminals can give limitations to capacitors max Irms rating / applicable current
  - Indicative max. current values by terminal style considered for ICEL S.r.l. power capacitor:
    - Tinned copper leads 0.8mm diameter = about 8A
    - Tinned copper leads 1.0mm diameter = about 10,5A
    - Tinned copper leads 1.2mm diameter = about 14A
    - Lugs up to around 35÷40A depending on type and shape

Current

- When working near rated maximum operating temperatures, due to power dissipation, the following max ΔT shall be considered for safety reasons (polypropylene capacitors)
  - ≤ 10°C at +85°C Tamb in general
  - ≤ 5°C at +85°C Tamb general purpose single metallized, not designed for power applications

- In specifications of capacitors series for power applications Irms ratings are typically referred to max ΔT of +15°C from Tamb to Ttot (operation at rated power, current and voltage, natural cooling, +70°C or +85°C observing voltage and current deratings)

- As a general indication for rated max Irms
  - ΔT around +10°C can be obtained applying Irms reduced to about 0.82 x Irms max.
  - ΔT around +5°C can be obtained applying Irms reduced to about 0.58 x Irms max.

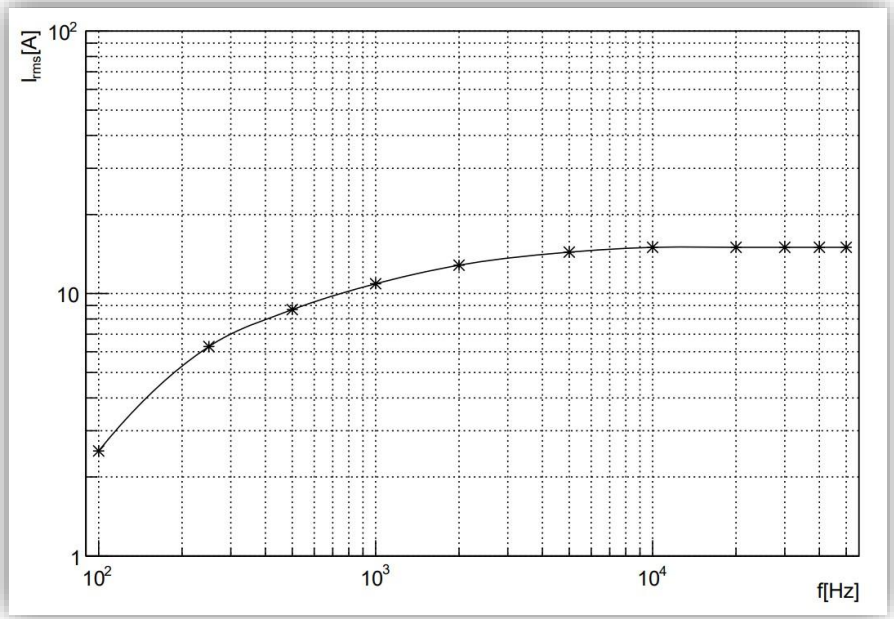
Power dissipation

- For a sinusoidal waveform

$$I_{rms} = 2\pi f \times C \times V_{rms}$$

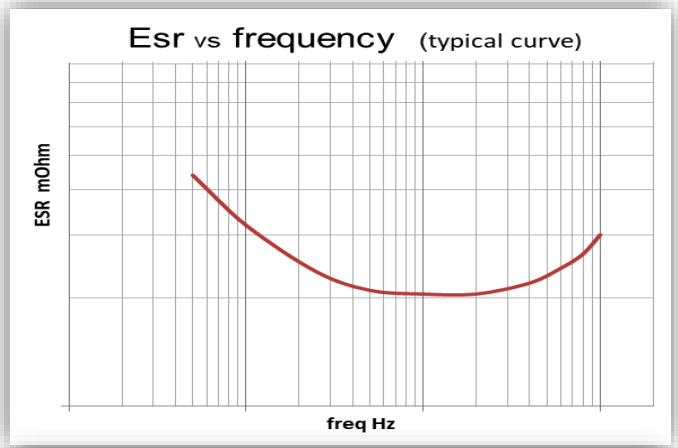
$$P = ESR \times I_{rms}^2$$
$$= V_{rms}^2 \times tg\delta \times 2\pi f \times C$$

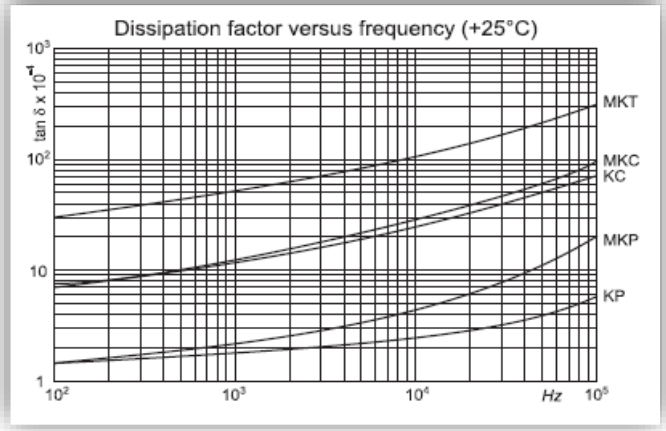
$$ESR = tg\delta / 2\pi f C$$



ESR and tgδ

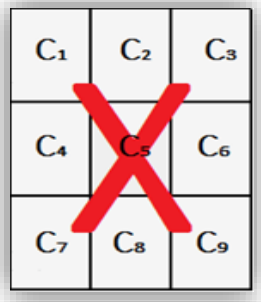
- ESR is the **resistive part of capacitors equivalent series circuit**
  - sum of **all that contribute resistivity**: resistivity of electrodes, internal connections, dielectric losses
- ESR is a **function of frequency, temperature and capacitance**
- ESR is **related to dissipation factor** tgδ: $ESR = tg\delta / 2\pi f C$
  - dissipation Factor (tgδ) is the power loss of a capacitor divided by the reactive power of the capacitor and changes with frequency and temperature

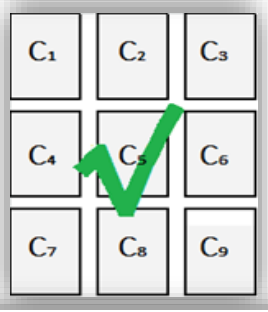


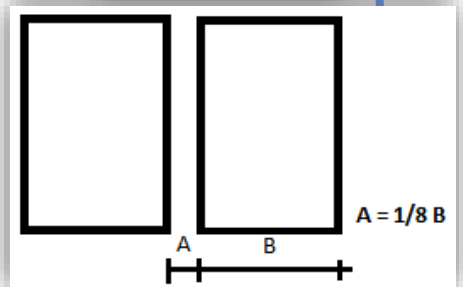


Capacitor in layout

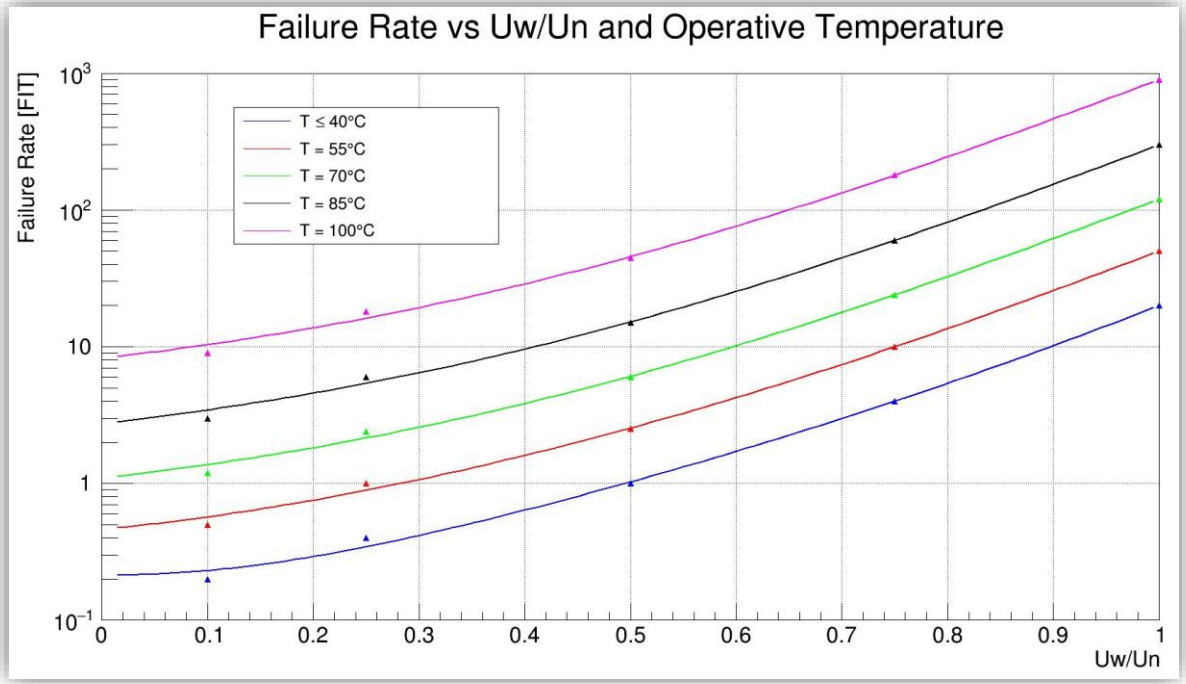
- Capacitor must not be installed in contact or very close to other components but with enough distance to allow proper airflow and cooling
  - contact to other components can cause mechanical stress under vibration or shocks or due to thermal expansion
- Capacitors shall be placed away from any source of heating to prevent high temperatures to compromise design reliability
  - the larger the capacitor is and the more it is stressed by voltage, current or temperature, the more important the correct design is
  - extra heating can also be consequence of strong magnetic fields inducing currents in metal parts
- Capacitors shall be in safe distance from heavy current conductors
  - the influence of other components must always be carefully evaluated
- Leads, especially large section lugs, dissipate heat but can also transfer heat into the capacitor
  - it is necessary to keep the connections cooler than the capacitor



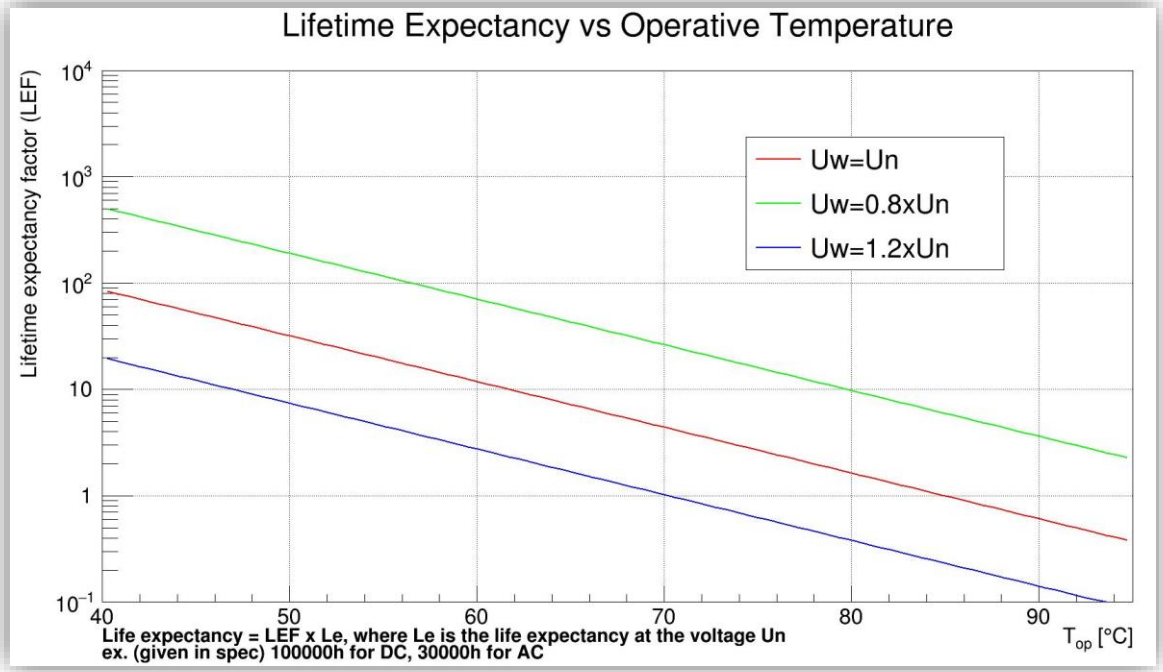




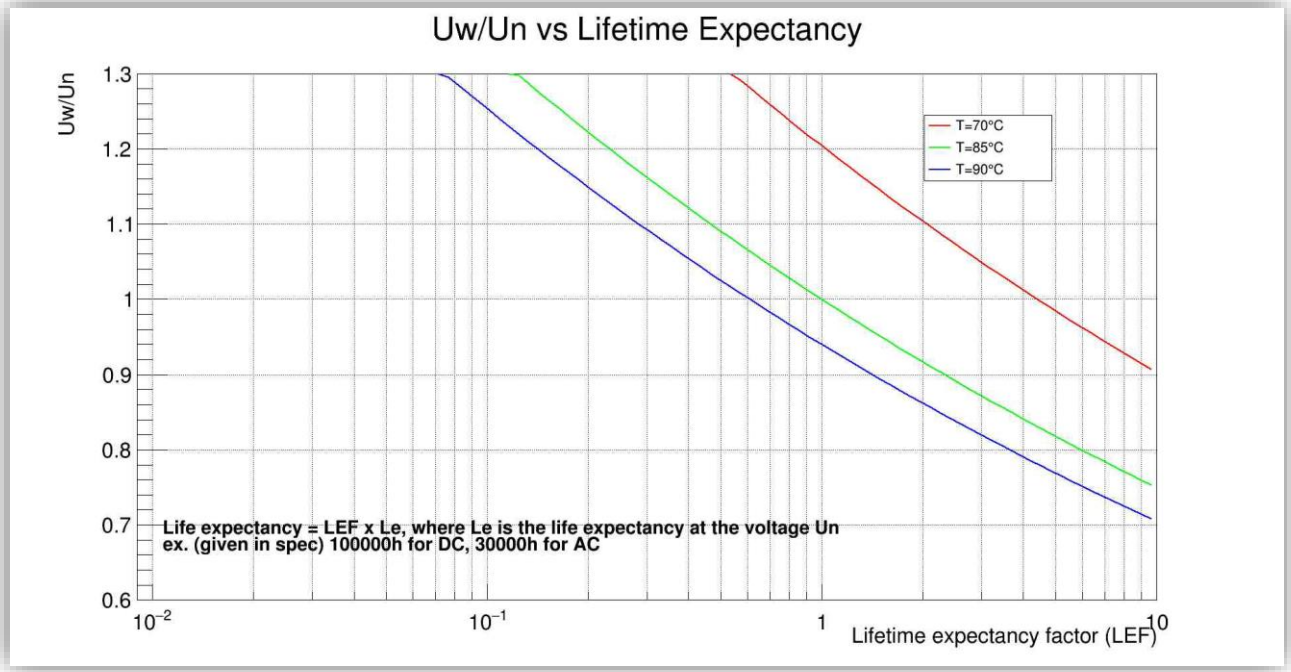
Failure Rate



Lifetime Expectancy vs Temperature



Uw/Un vs Lifetime Expectancy



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be active in choosing ***the passive***!

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