	Elaborado	Revisado	Aprobado
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Power Station. Inverter. PQ Capabilities

Registro de Cambios

Rev.	Fecha	Propósito	Descripción
01	13/06/2019	PARA APROBACION	PRIMERA EMISION

Application Note

PQ Curve Definition

Contents

1. Introduction.

The objective of this document is to define the capability curve of Power Electronics solar inverters describing the nature of their limitations.

2. PQ Curve Definition.

To determine the active and reactive powers a photovoltaic generator is able to deliver and to absorb, it is indispensable to know photovoltaic inverter's limits.

2.1. Thermal Limit

Inverter's thermal limit imposes a maximum working current.

After a specific operation time, the current circulation through the components leads into a heating which must be controlled in order to avoid they could be damaged. When the power is too high, the component is not able to dissipate so much energy and it is destroyed.

For instance, the powers managed by the semiconductor devices are in many cases of a considerable magnitude. Moreover, the problem is made worse taking into account that they are small devices, and then the dissipation of the heat produced is more difficult.

Since that heating is directly associated with the current in circulation which is linked in its turn with the voltage between terminals, the manufacturer defines the electrical limit parameters as well as the maximum working temperature.

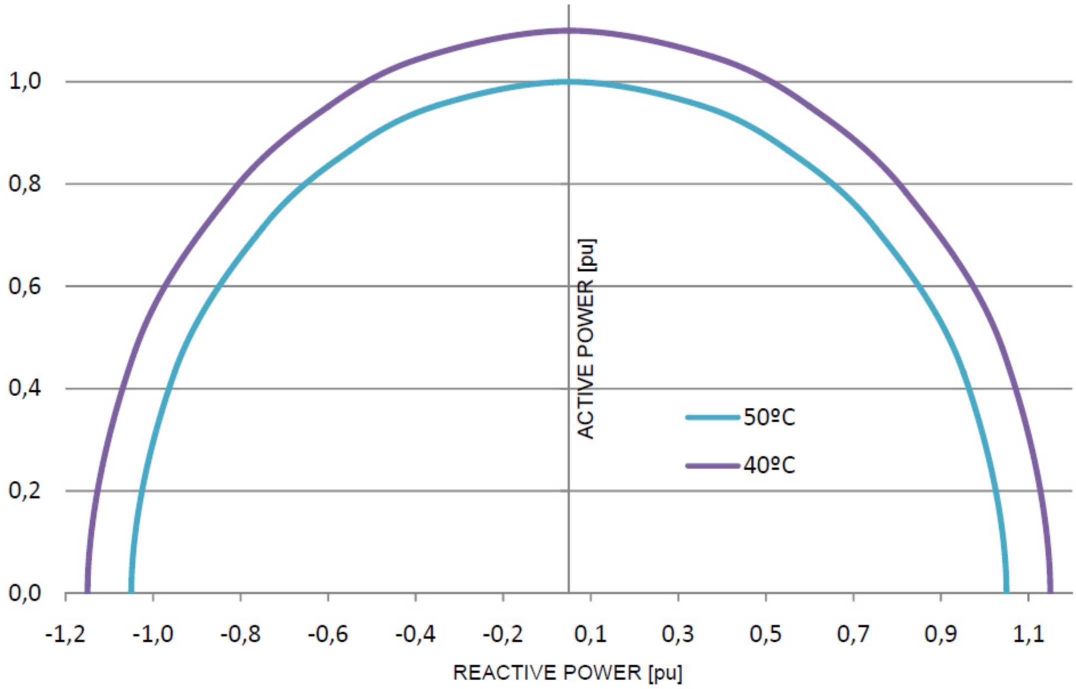

Figure 1. Thermal Limit. PQ Curve.

The blue curve represents the capability of the equipment at 50ºC. As the temperature increases the current injection by heating is limited and, consequently, decreases the radius of the curve.

The purple curve represents the maximum capacity of the equipment and it is obtained up to a maximum temperature of 40ºC.

HEC equipments are designed to offer the maximum power at 50ºC, that is, in order to achieve
the thermal and the electrical limit at 50ºC.

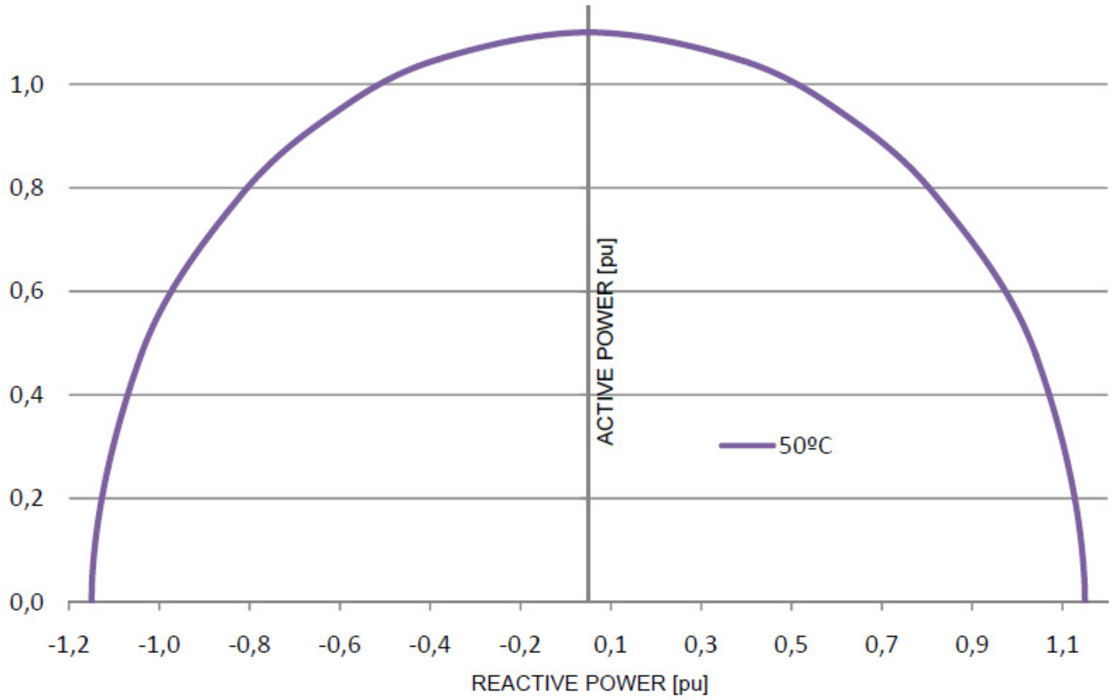

Figure 2. Thermal Limit coincident with Electrical Limit. PQ Curve.

2.2. Electrical Limit

Maximum working currents and voltages are imposed by the electrical limitation (voltage and current) of components, determined by the manufacturer in the design stage their good performance, and in turn imposes a limit of active and reactive power delivered.

$$P^2 + Q^2 = (\sqrt{3} \cdot V_{GRID} \cdot I_{INJECTED})^2 = S^2 \quad (2.2.1)$$

Where V_{GRID} and $I_{INJECTED}$ are line values.

The equation 2.2.1. is identified with the equation of a circumference ($x^2 + y^2 = r^2$) and defines the PQ curve characteristic of a generator.

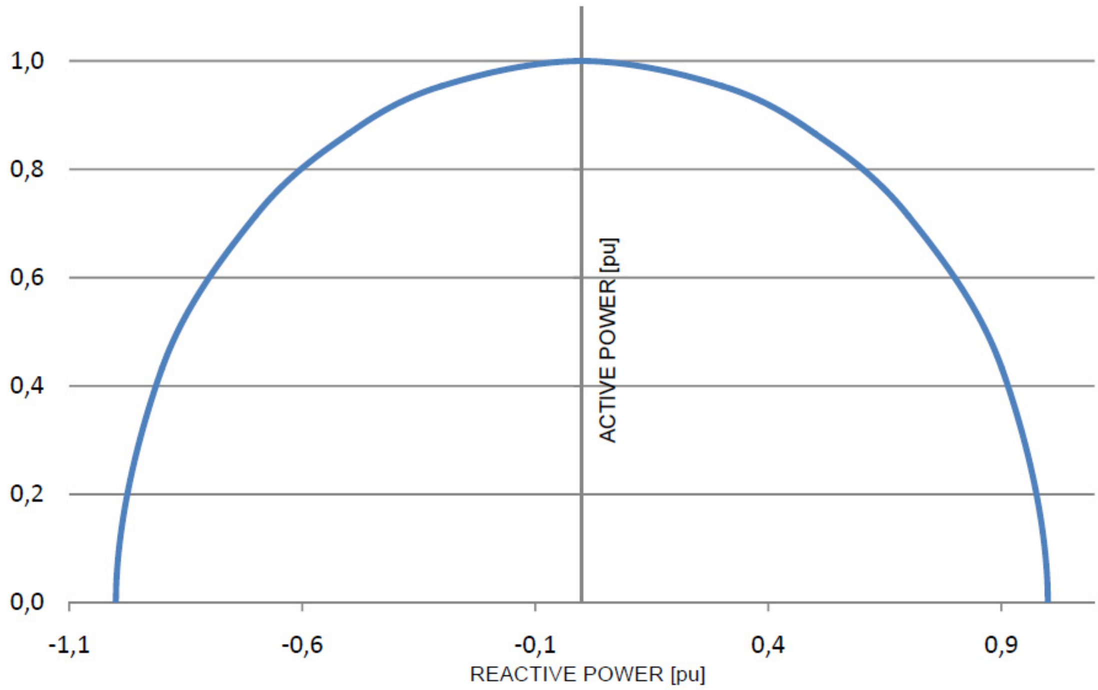

Figure 3. Electrical Limit. PQ Curve.

2.3. Voltage Limit

The voltage limit at the inverter is dictated, on the one hand, by the minimum input DC voltage, depending on the configuration of solar farm and on the irradiance and temperature conditions, and, on the other hand, by the AC output voltage imposed by the grid voltage.

In Figure 2 a photovoltaic grid connected inverter is shown. The reactance X indicated corresponds essentially to the impedance of the LCL filter.

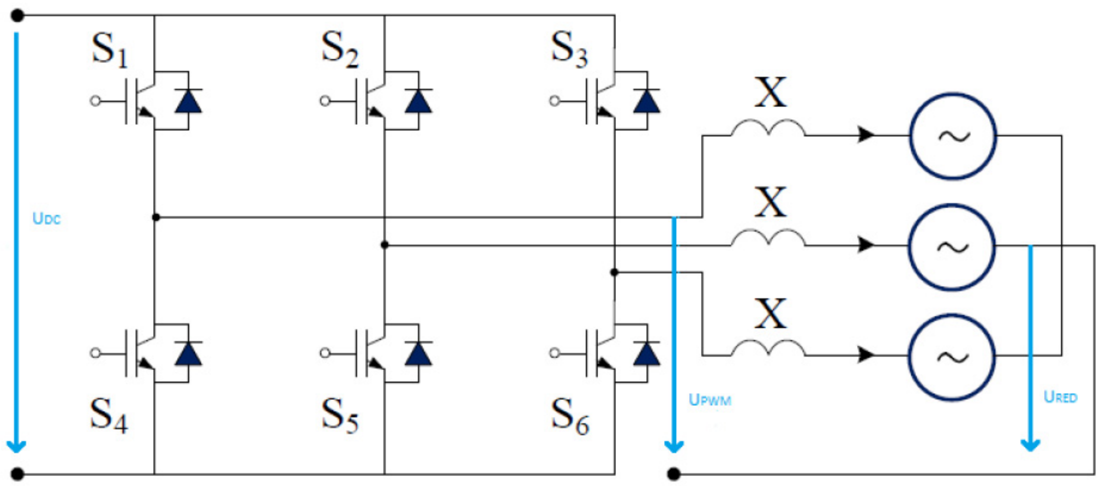

Figure 4. Inverter Scheme.

The representative single phase scheme equivalent of Figure 2 would be as follows:

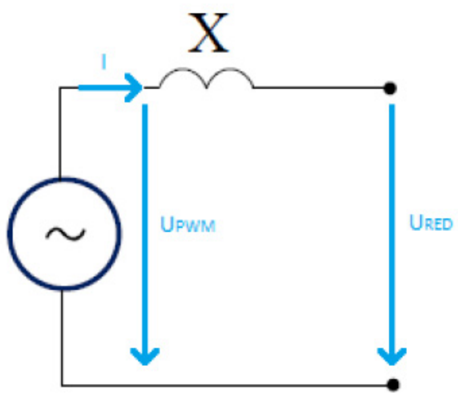

Figure 5. Equivalent Scheme.

Applying the second law of Kirchhoff the following relation between voltages is obtained:

$$U_{PWM} = U_{RED} + jXI_I \quad (2.3.1)$$

Then, the phasor representation of this equation is shown if inductive current is injected (assuming positive direct sequence clockwise):

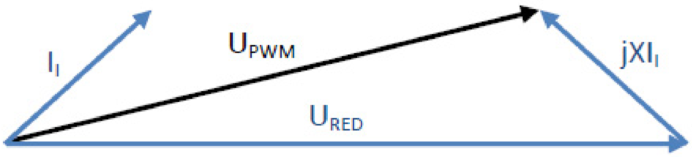

Figure 6. Phasor Diagram. Inductive Current Injection.

The phasor diagram allows easily detecting the voltage drop at the inverter output with inductive current injection.

The equation expressing the relation between the DC and the AC voltage is:

$$\sqrt{2}U_{PWM} \leq U_{DC} \quad (2.3.2)$$

Where UPWM is RMS and line voltage.

So, in this case, there is no voltage limit for the inductive current injection because the greater the current supplied is, the lower the output voltage of the inverter (U_{PWM}) is with respect to the output voltage (U_{RED}), the lower the voltage required to input (U_{DC}) is and, therefore, the voltage ratio more amply is complied.

Then, the phasor representation is illustrated if capacitive current is injected:

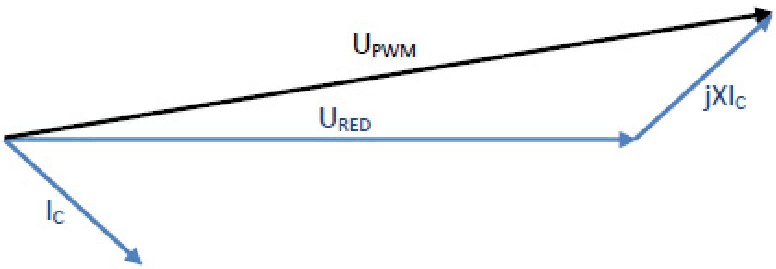

Figure 7. Phasor Diagram. Capacitive Current Injection.

The latter phasor diagram allows easily detecting the increase in output voltage of the inverter with capacitive current injection.

The greater the capacitive reactive current supplied is, the greater the required voltage to the inverter output is whose peak value ($\sqrt{2}U_{PWM}$) must be less than the DC voltage available at the input (equation 2.3.2.).

Thus, it is shown that the DC voltage available limits the capacitive reactive current injection because it causes to increase the output voltage sacrificing voltages' ratio.

However, no limit is observed for inductive current injected since the greater the power injected is more loosely the equation 2.3.2. is complied.

For example, an HEC inverter with output AC voltage of 400V has the following capability curves.

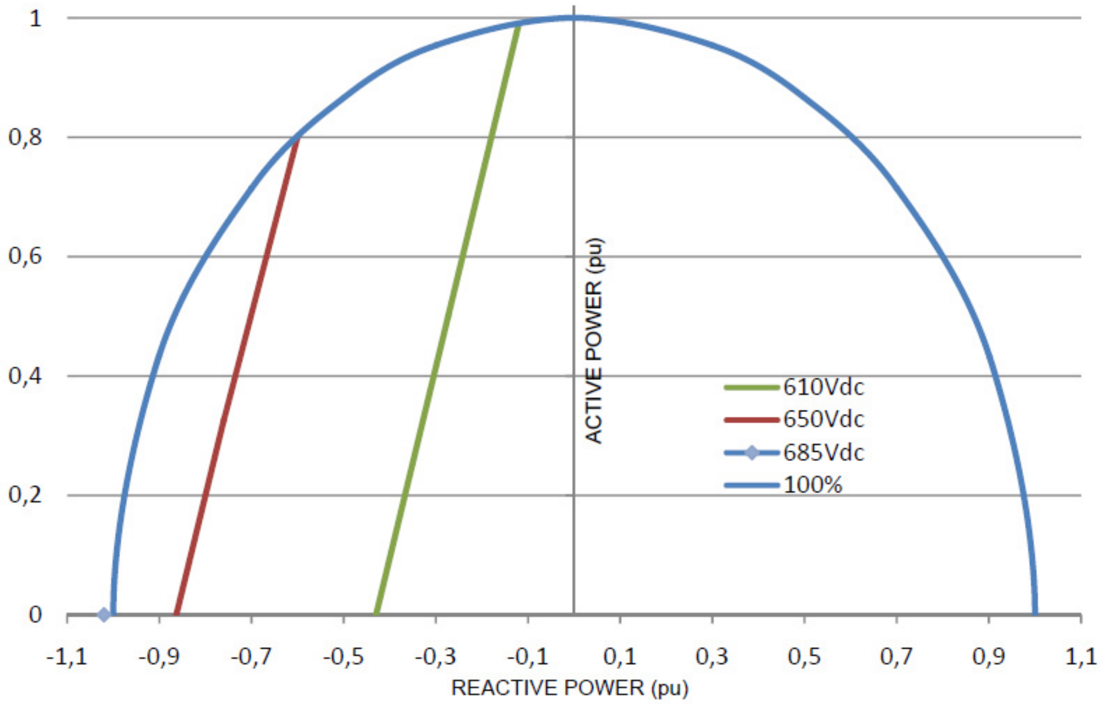

Figure 8. Voltage Limit. PQ Curve.

From a minimum DC voltage of 685V inverter only limits electrically.

For a better use of voltage and, in parallel, a lower limitation of capacitive reactive power delivery, an extension of the operating range based on reconfiguring modulation techniques is performed.

Thus, an HEC inverter with output AC voltage of 400V has the following capability curves.

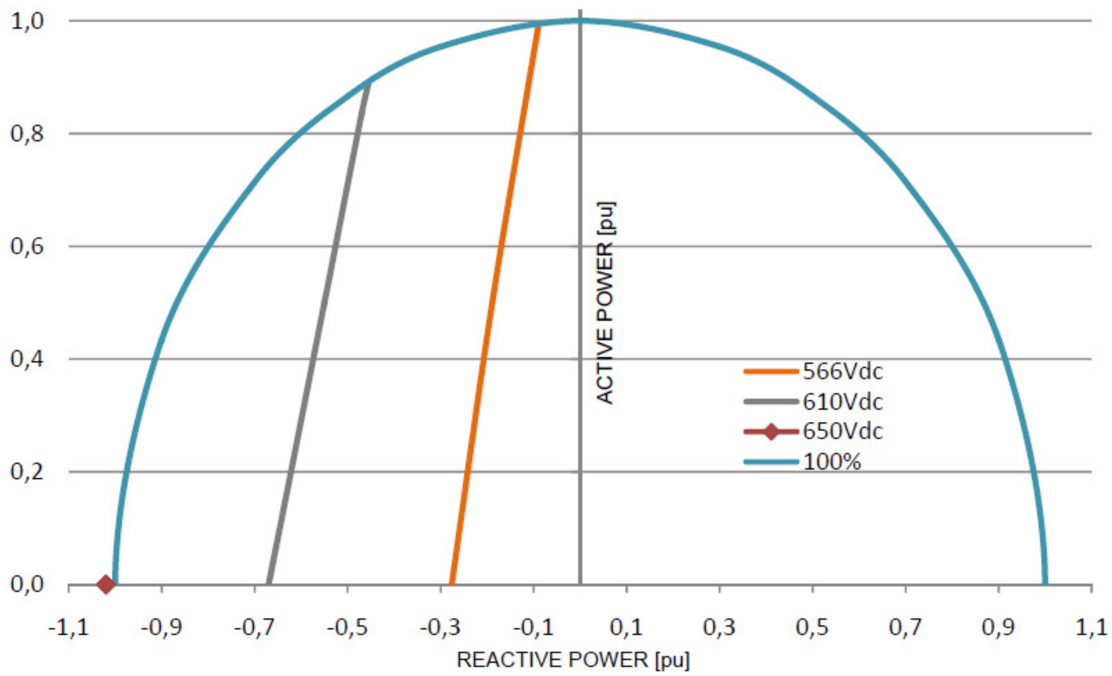

Figure 9. Voltage Limit. PQ Curve with Extended Range.

From a minimum DC voltage of 650V inverter only limits electrically.

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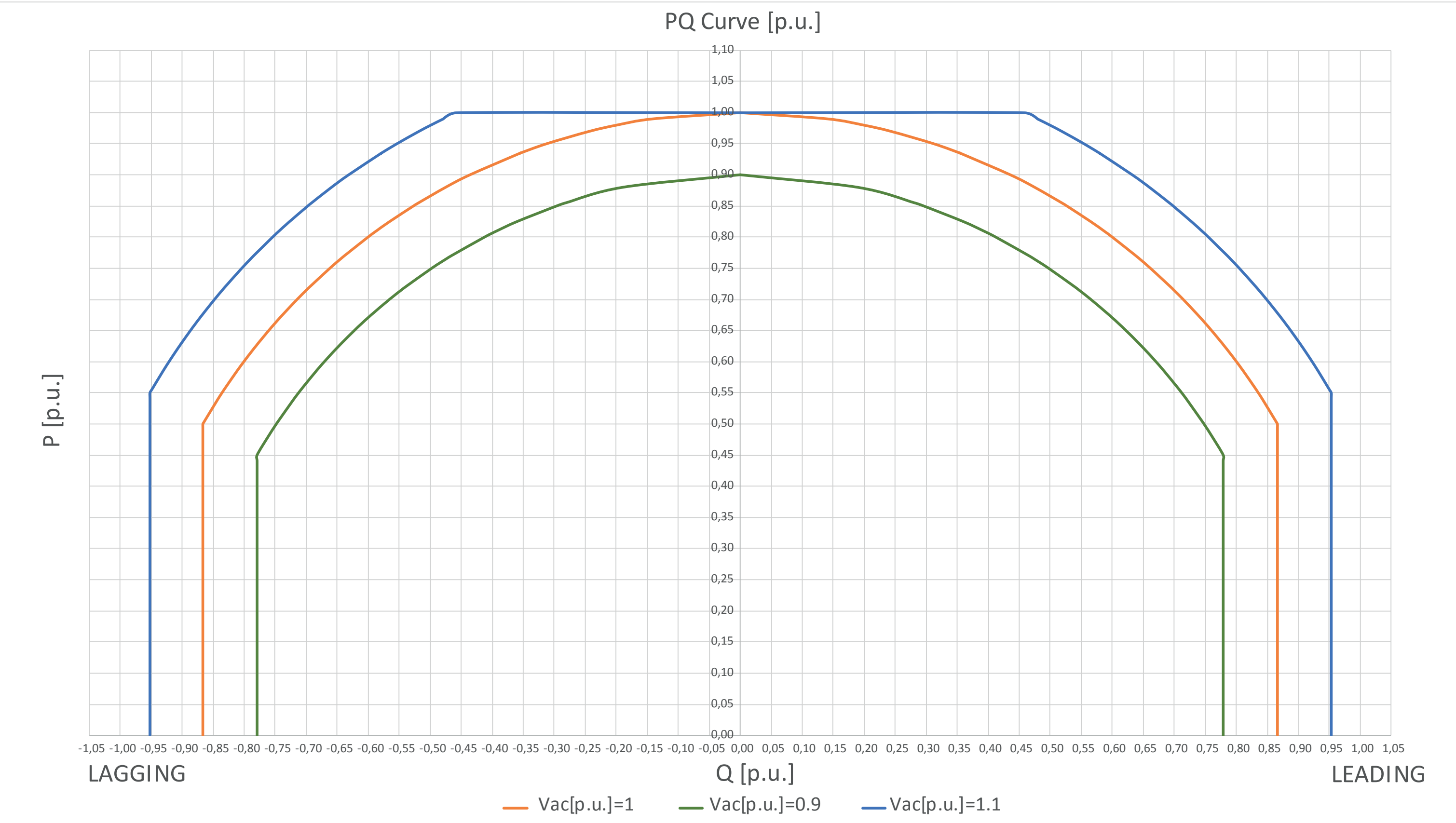
TECHNICAL CHARACTERISTICS - PQ CURVE

PQ CURVE



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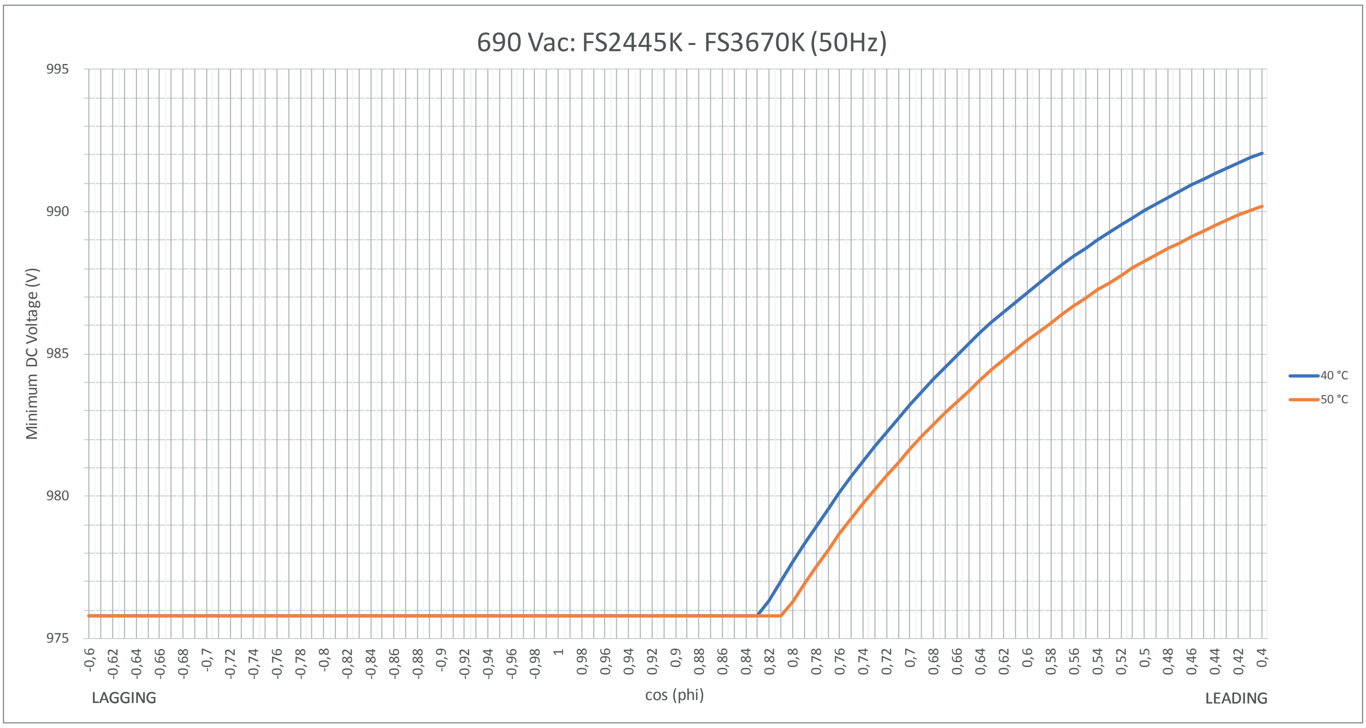
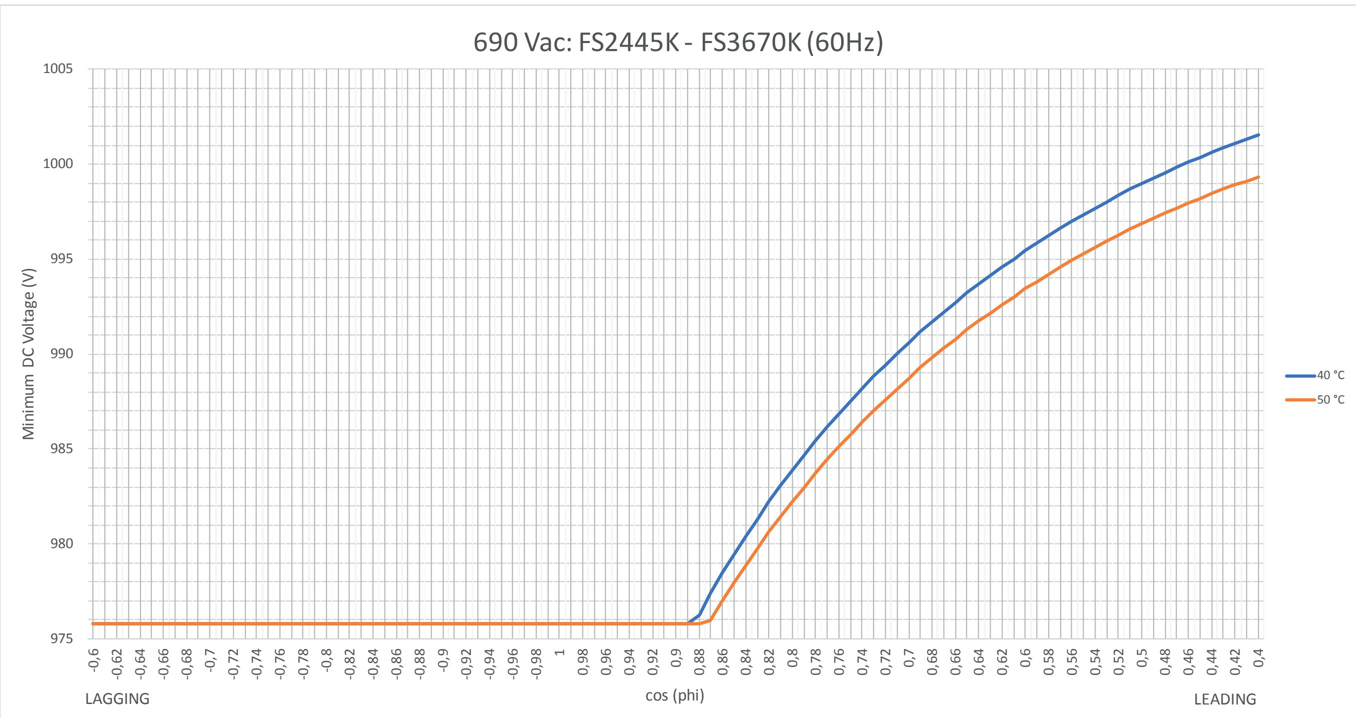
COS (Φ) VS MINIMUM DC VOLTAGE

690Vac - 50Hz



690Vac - 60Hz



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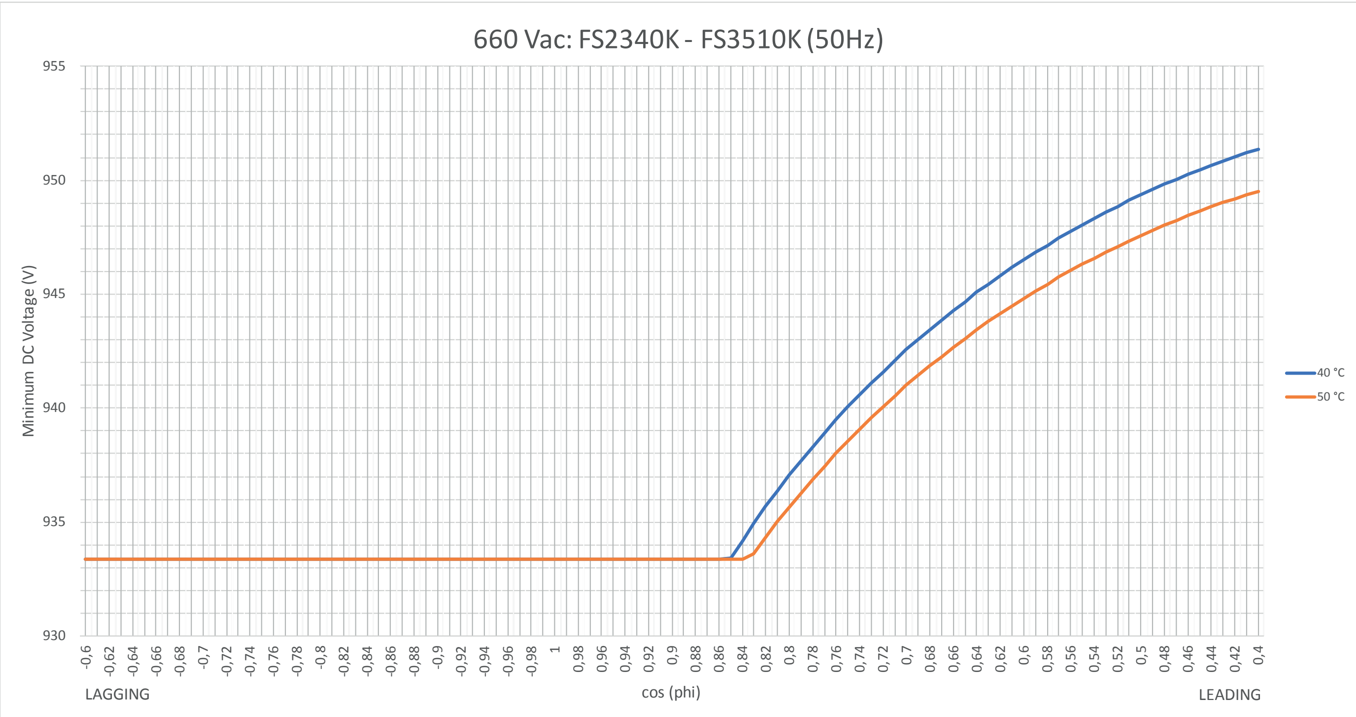
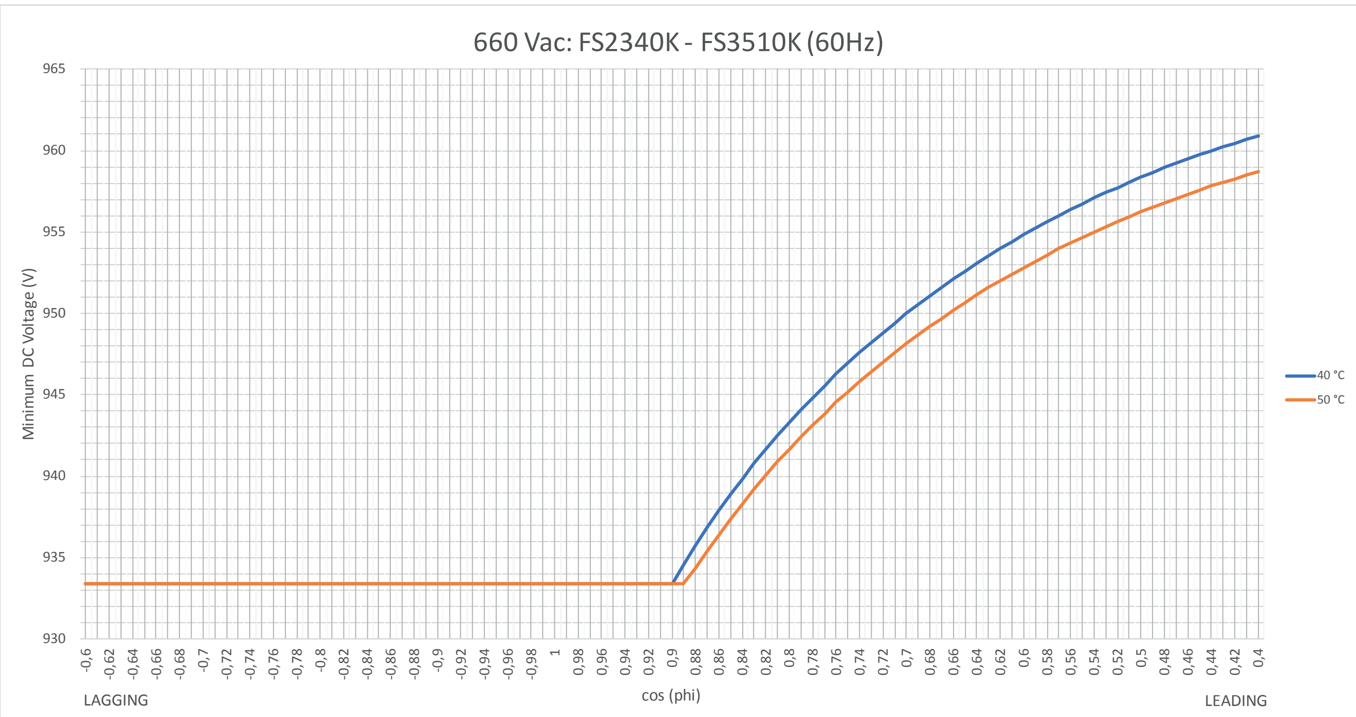
COS (Φ) VS MINIMUM DC VOLTAGE

660Vac - 50Hz



660Vac - 60Hz



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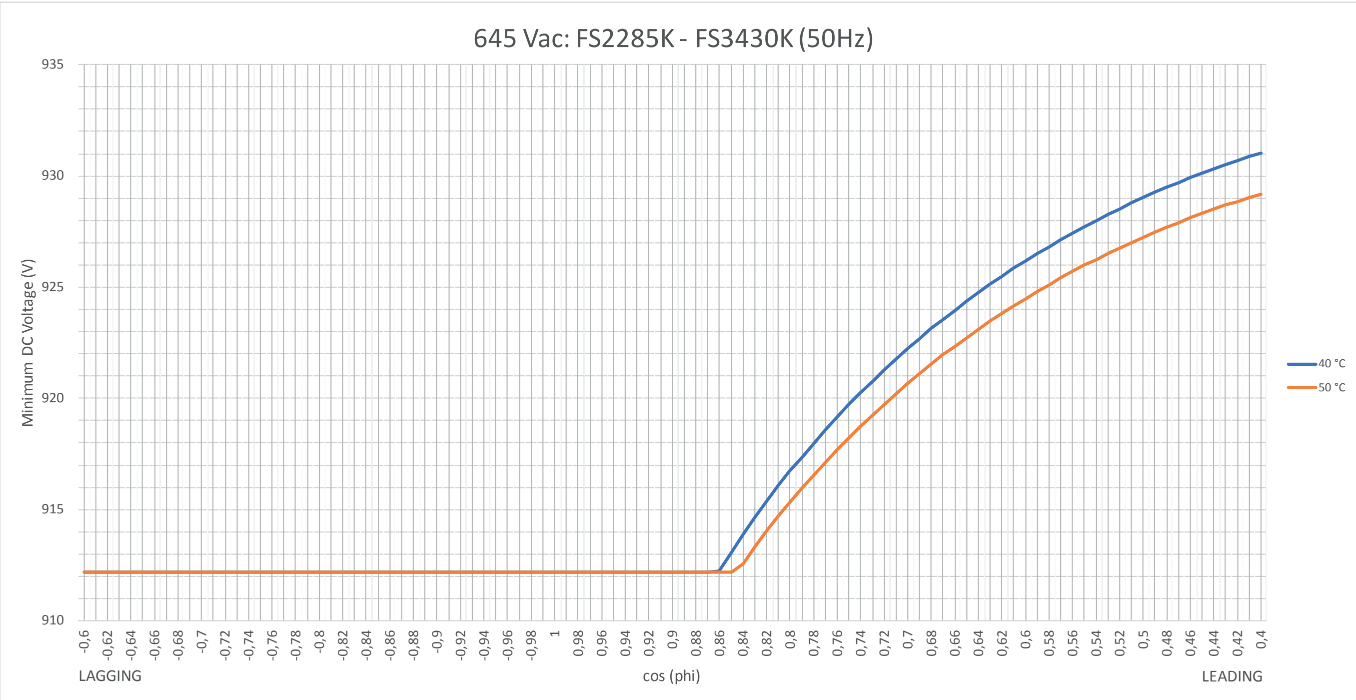
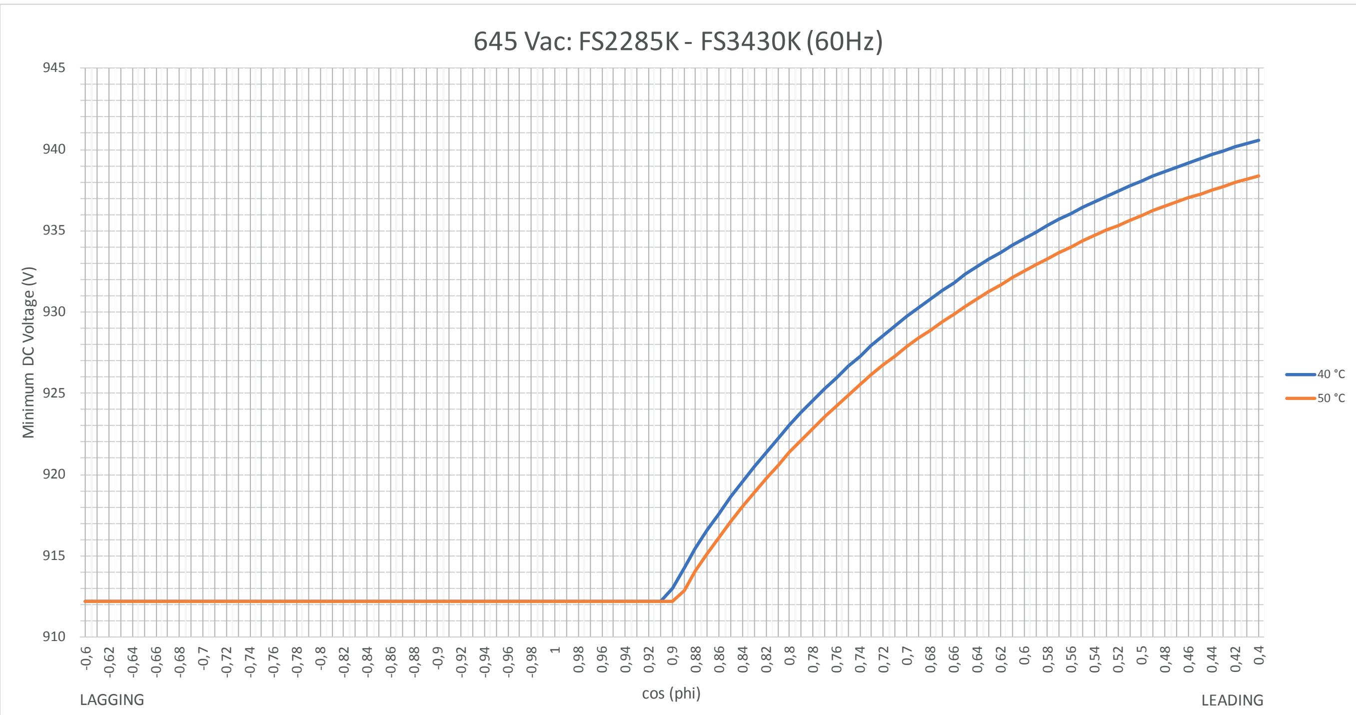
COS (Φ) VS MINIMUM DC VOLTAGE

645Vac - 50Hz



645Vac - 60Hz



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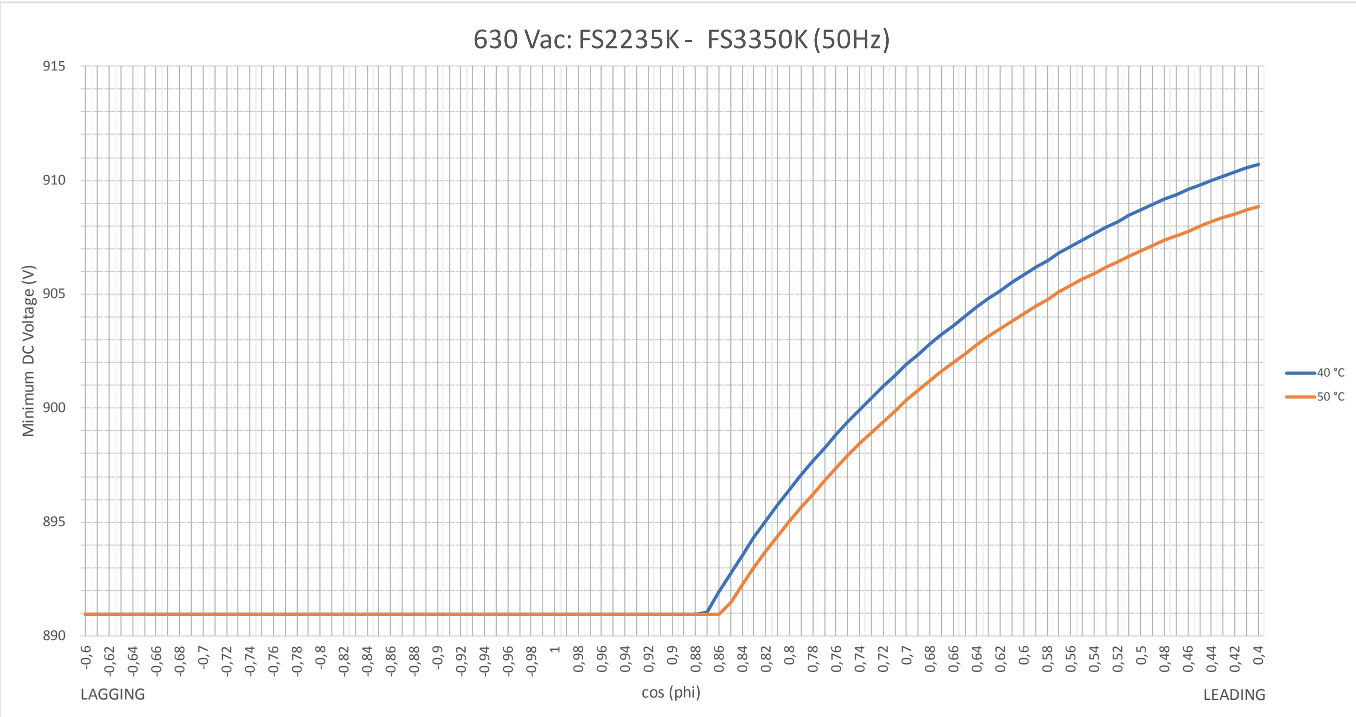
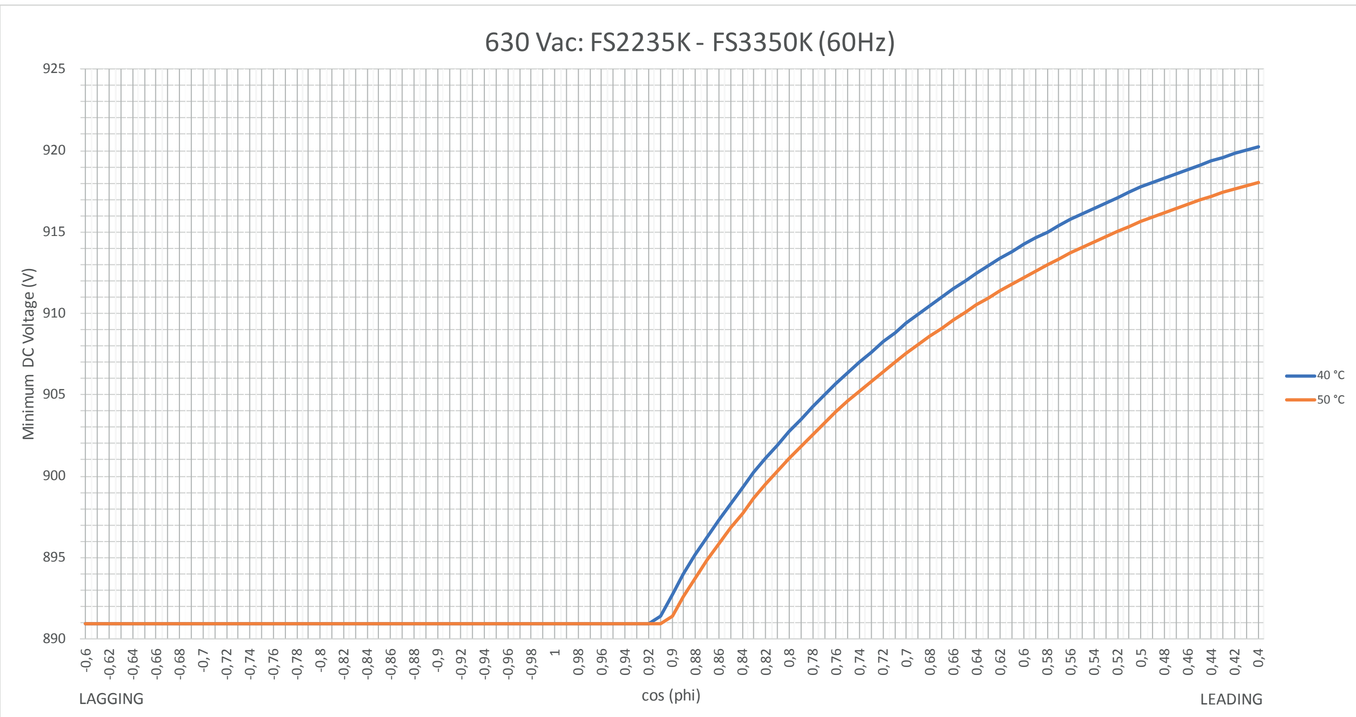
COS (Φ) VS MINIMUM DC VOLTAGE

630Vac - 50Hz



630Vac - 60Hz



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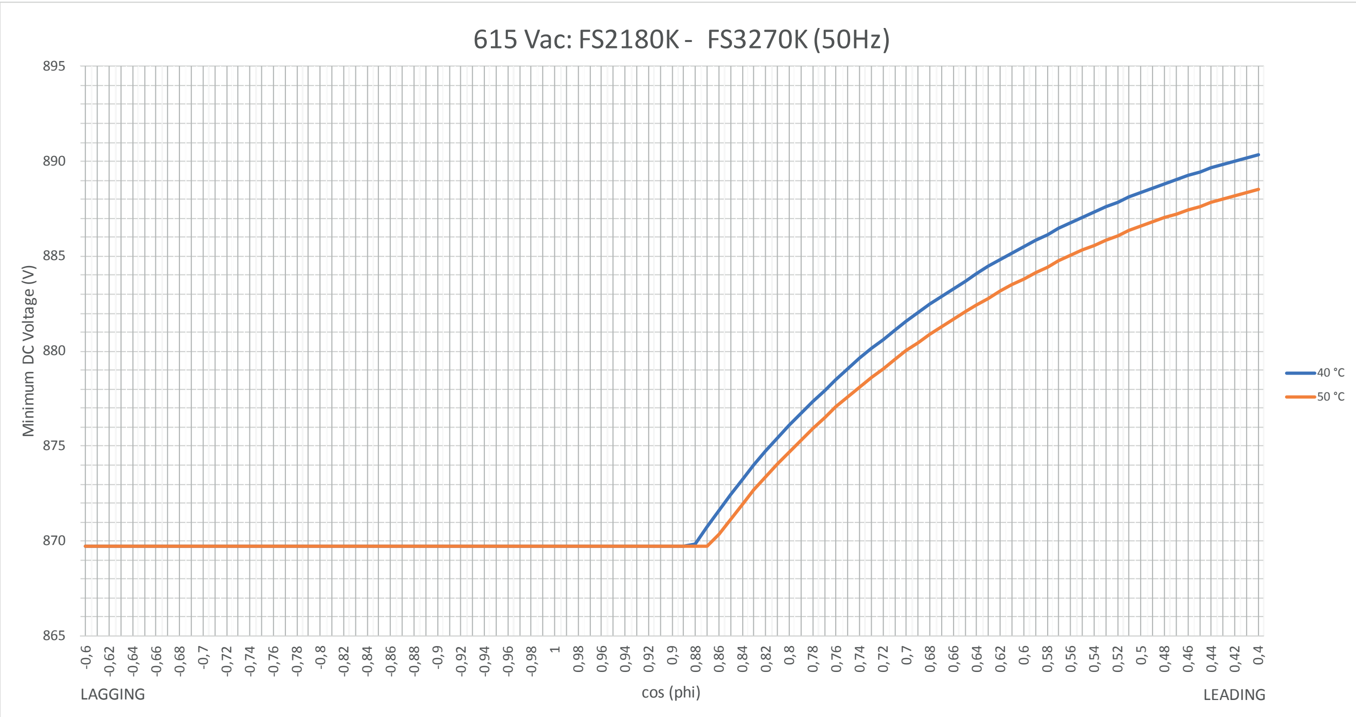
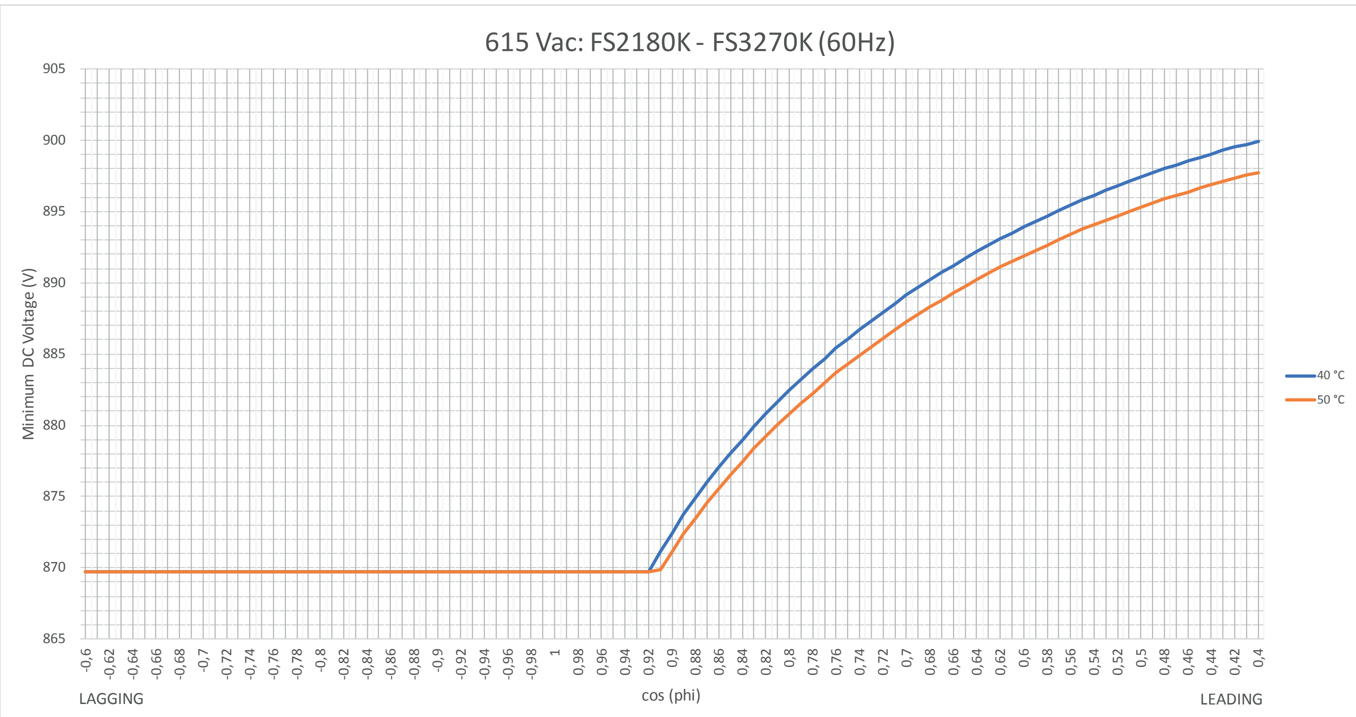
COS (Φ) VS MINIMUM DC VOLTAGE

615Vac - 50Hz



615Vac - 60Hz



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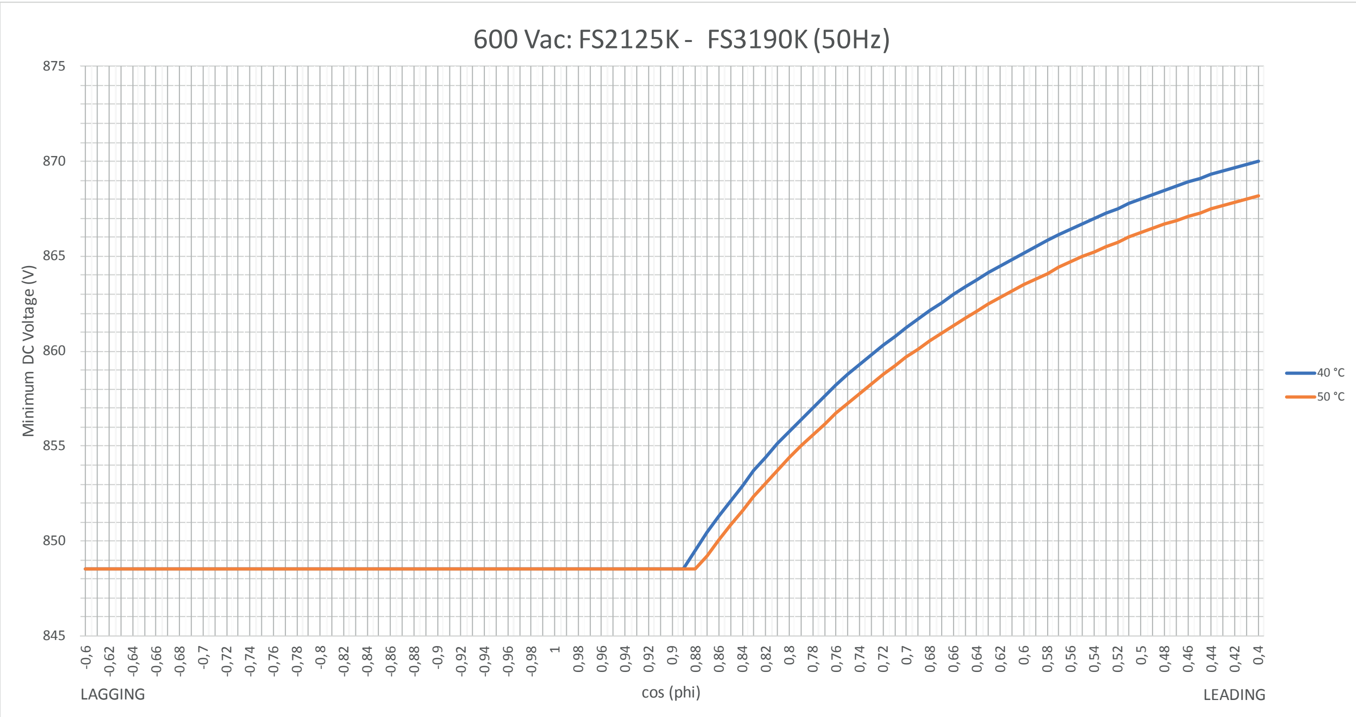
COS (Φ) VS MINIMUM DC VOLTAGE

600Vac - 50Hz



600Vac - 60Hz