

# Alternator as a voltage Generating source and its response to the leading power factor loads

Presentation by:  
Jay Deshpande (Engineered Solutions- Mission Critical)  
Kohler Power Systems  
Washington, DC metro area



# Study Material & References

- Kohler Learning Center
- Uninterruptible Power Supplies Ltd, UK (Kohler Company)
- Impact of Leading Power Factor on Data Center Generator Systems (APC- Schneider Electric White Paper)
- [www.powerelectronics.com](http://www.powerelectronics.com)
- [https://wiki.openelectrical.org/index.php?title=Power\\_Factor](https://wiki.openelectrical.org/index.php?title=Power_Factor)
- Electrical Machinery, by Dr. P. S. Bimbhra
- A Text-Book of Electrical Technology (VOL I & II), by B. L. Theraja & A. K. Theraja



# Leading Power factor loads- examples

- Capacitors that are used in various facilities to improve the power factor (reduced electricity bill from the utility)
- High-intensity discharge (HID) or fluorescent lamps with capacitor starters (ignitors) e.g. garage lighting
- Harmonic limiting capacitor filters used with the non-linear type loads e.g. UPS
- In a GenSet paralleling application, when a large leading power factor load is applied to the first GenSet online.
- Any other examples?

# Presentation Outline

- Power Triangle – KW, KVAR, KVA & Power factor
- Basic Principal behind the operation of the alternator, AVR & Exciter assembly
- What happens when an alternator is subjected to the leading power factor loads
- Theoretical derivation of the alternator capability curve
- Analyze the alternator capability curve published by the manufacturers
- Alternator's response to leading power factor loads: facts to remember
- Recommendations : open to discussion

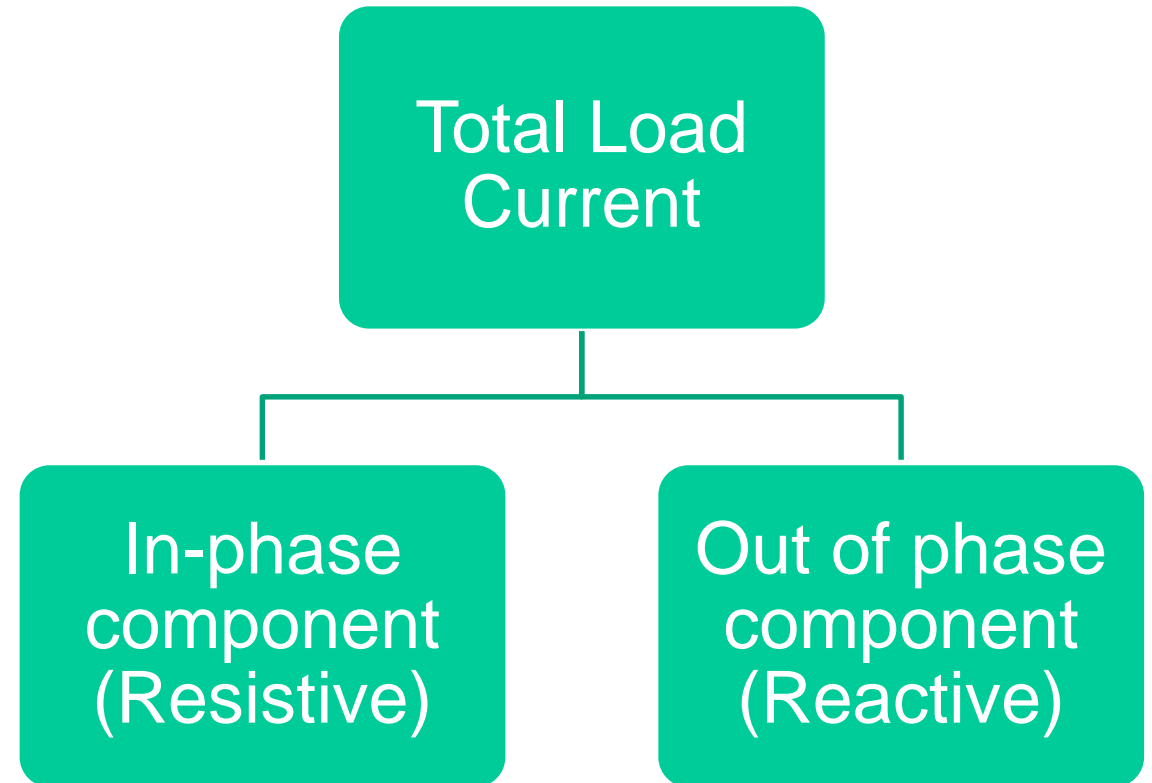


# Ten minutes refresher course!

- GenSet produces voltage
- Load establishes current
- Load characteristics establish the current characteristics.
- e.g. Purely resistive load establishes a current waveform that is in phase with the voltage waveform.
  - 100% of the current is utilized in transferring watts power to the load
- However, not all loads utilize 100% of the current towards the watts power consumption.
  - Out of phase current component, which is not aligned in time with the voltage waveform.

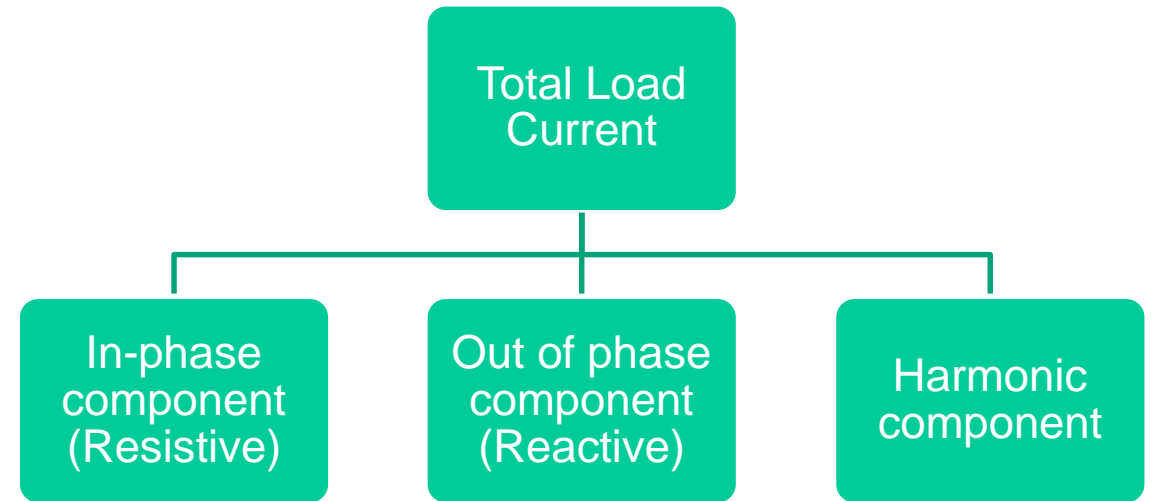
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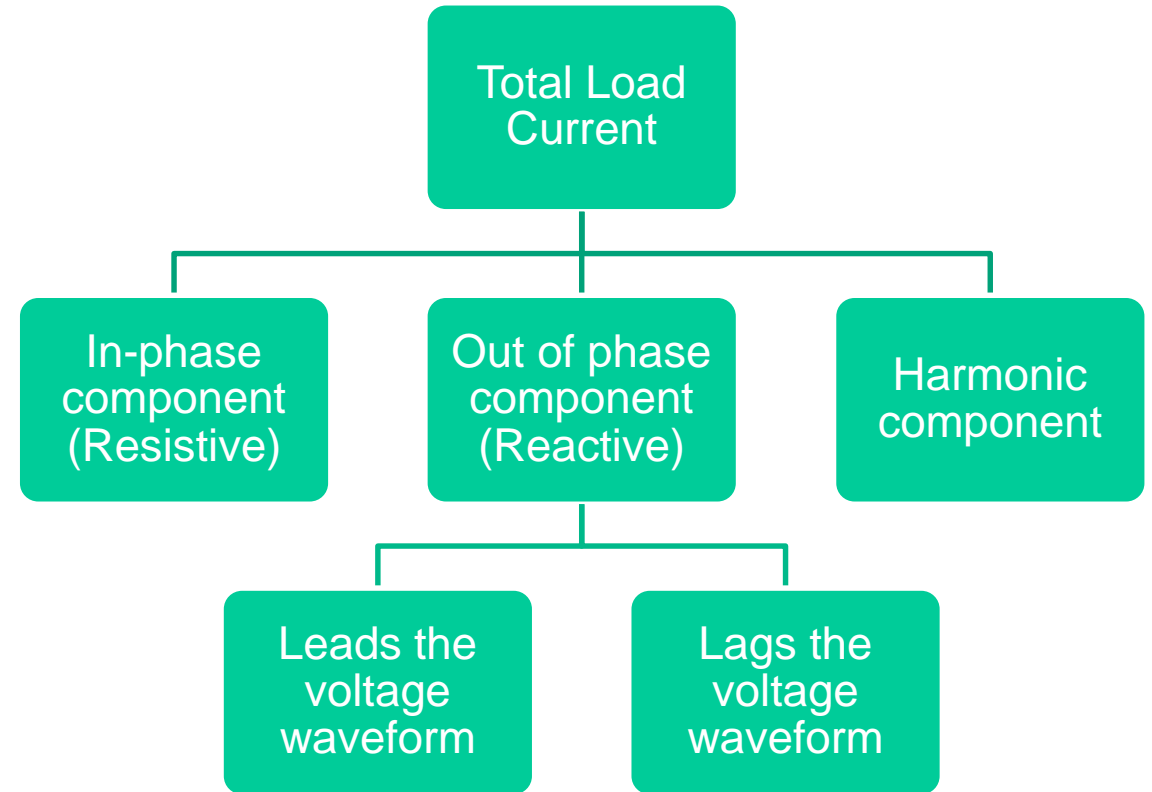
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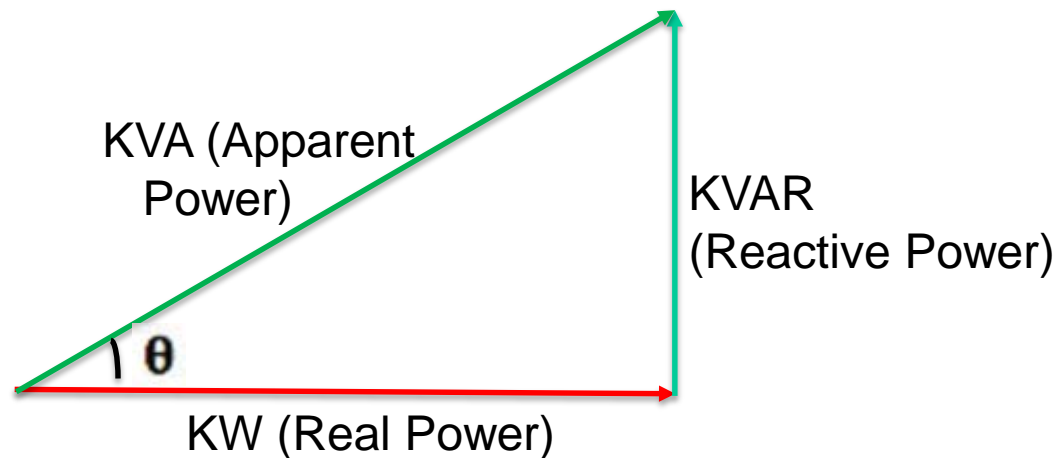
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# Power Triangle

## Power Triangle

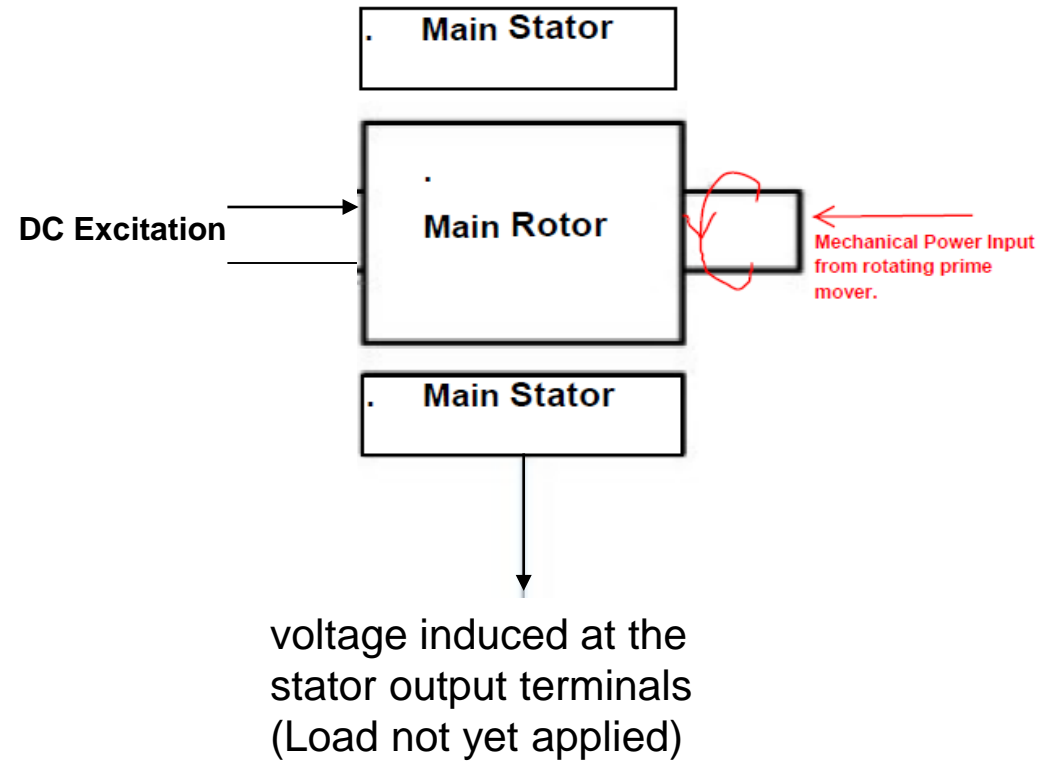


$$\cos \theta = KW / KVA$$

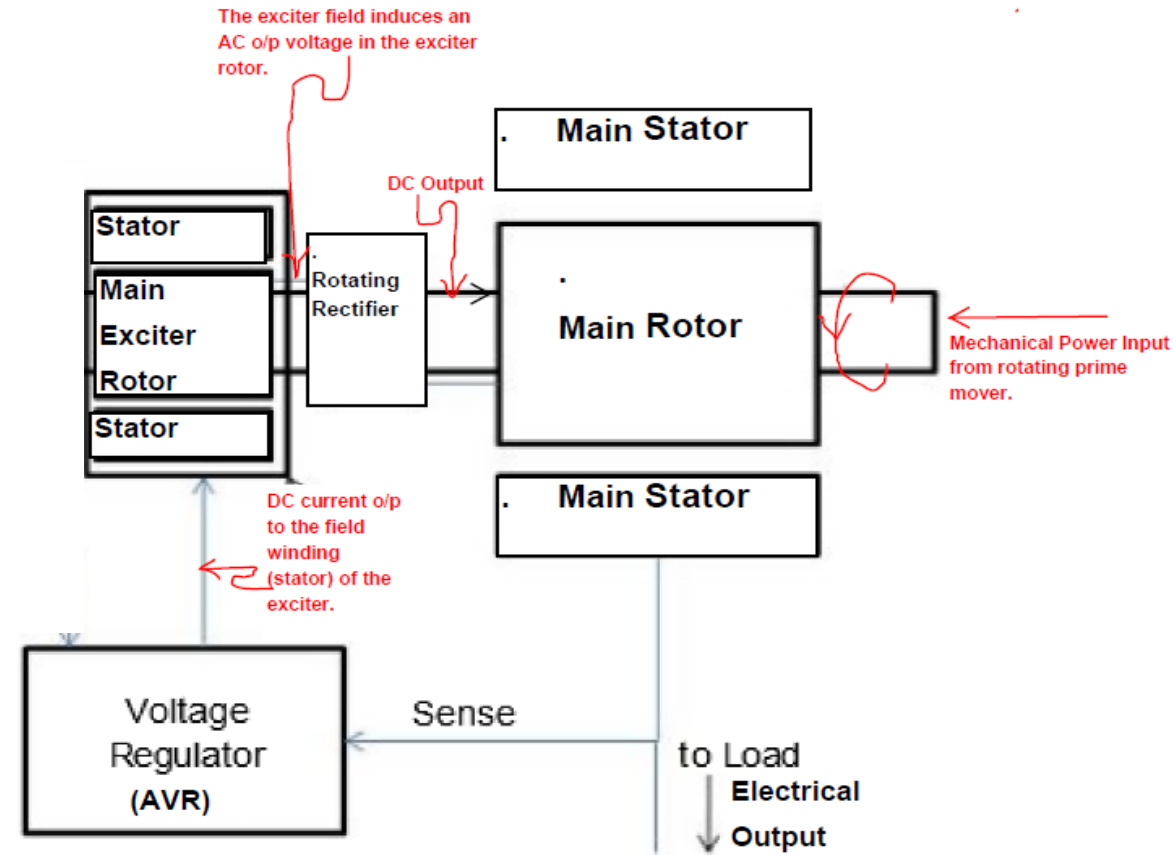
## Power Factor

- It is a cosine of an angle between the voltage and current.
- When expressed as the power transferred to the load by the resistive and reactive components of the total load current → Power Triangle

# Basic principle - alternator as a voltage generating source

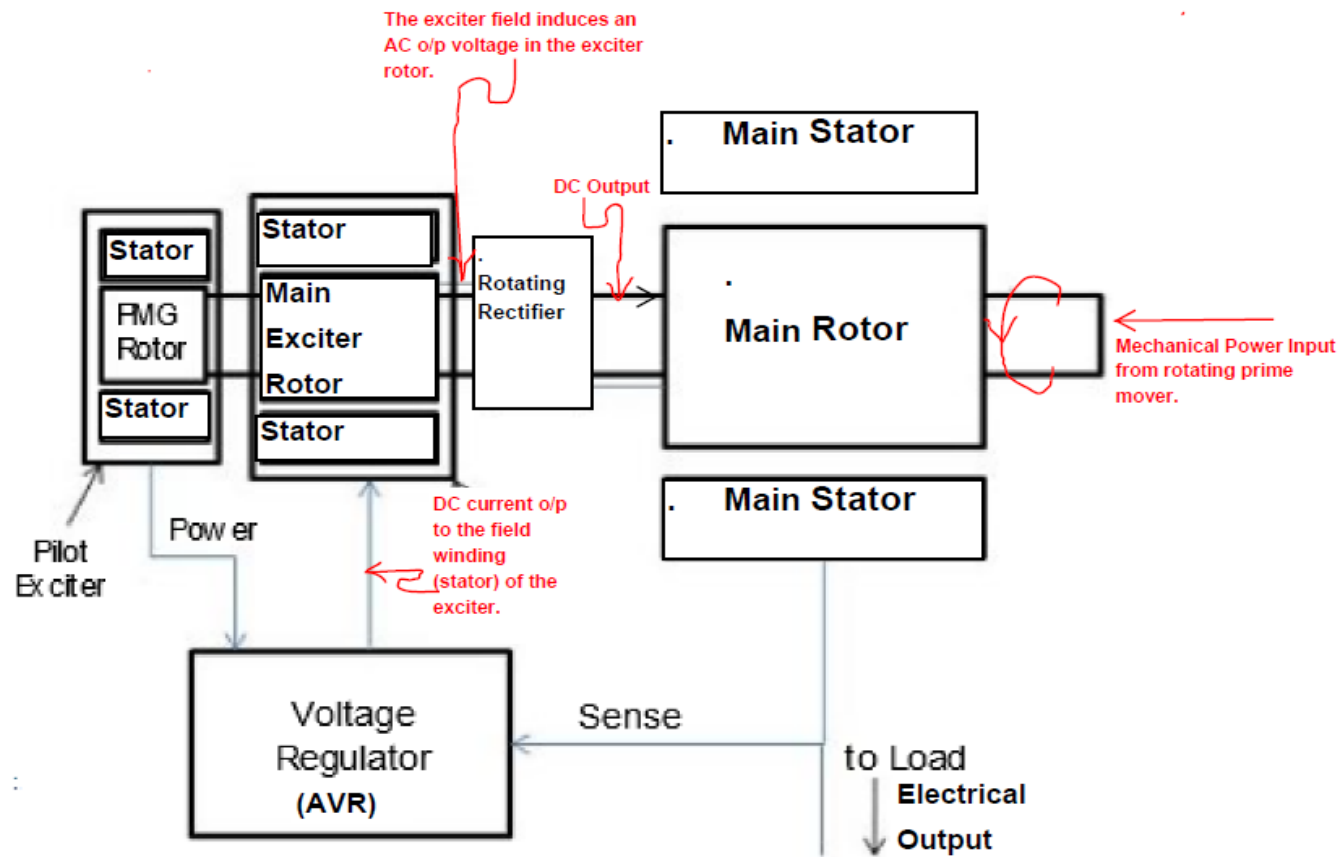


# Basic principle - Alternator as a voltage generating source



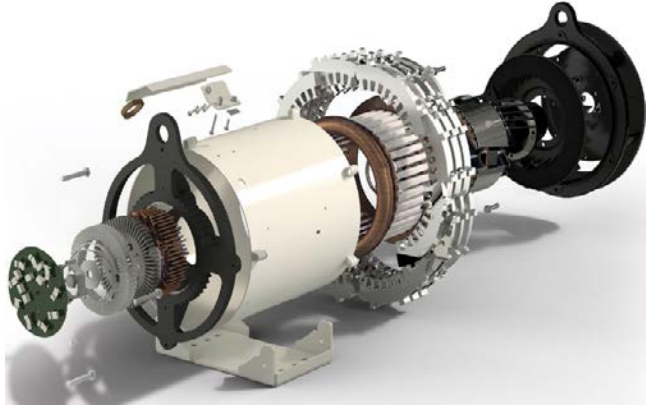
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# Basic principle - alternator as a voltage generating source



- AVR function: To regulate the voltage at its rated value under the varying load conditions.
- By increasing/decreasing the excitation current, the alternator can supply increased/decreased power (KVA) at the desired nominal (rated) voltage.

# Alternator



## Automatic Voltage Regulator (AVR):

Regulates the alternator output voltage at its rated value under the varying load conditions.

AVR controls the main rotor magnetic field by changing the excitation current

AVR → excitation current change → main rotor magnetic field → regulates the alternator (stator) output voltage

# Engine



## Frequency Governor (GOV):

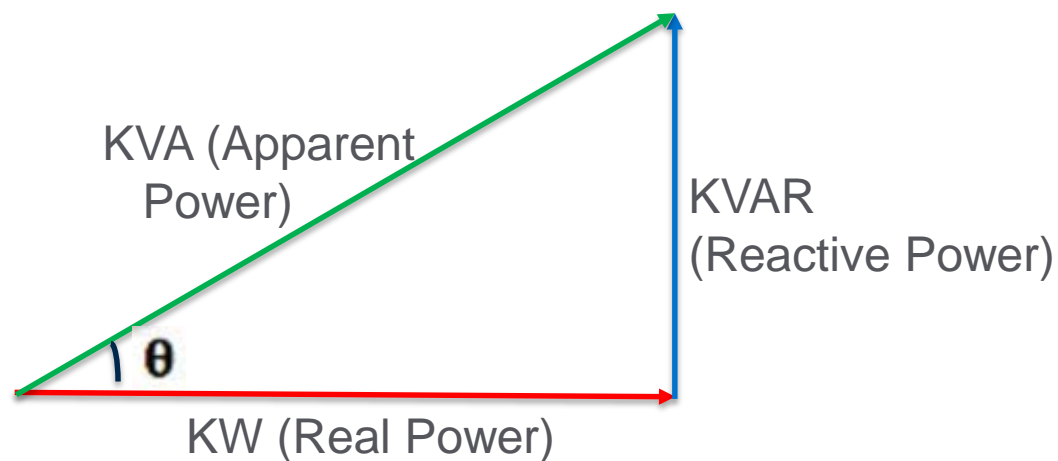
Regulates the output frequency at its rated value under the varying load conditions

Governor controls the engine speed by changing the fuel supply

GOV → fuel change → engine speed → regulates the output frequency

# Power Triangle

## Power Triangle

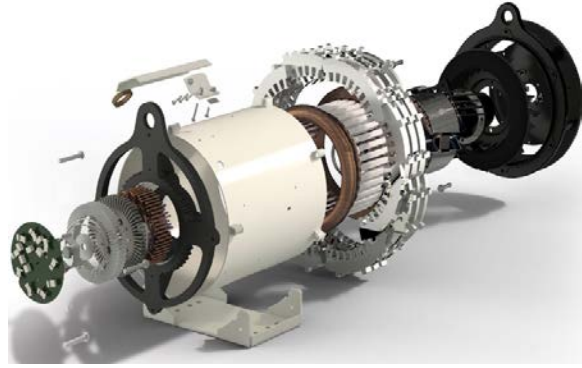


$$\cos \theta = KW / KVA$$

## Power Factor

- It is the Cosine of an angle between the voltage and current.
- The ratio of real power consumed by the load (kW) to the apparent power (KVA) delivered to the load in an AC circuit.

# Alternator



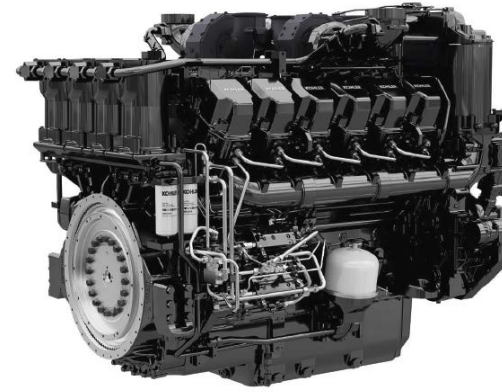
**Automatic Voltage Regulator (AVR):**  
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KVAR demand by the load is seen by the alternator

# Engine



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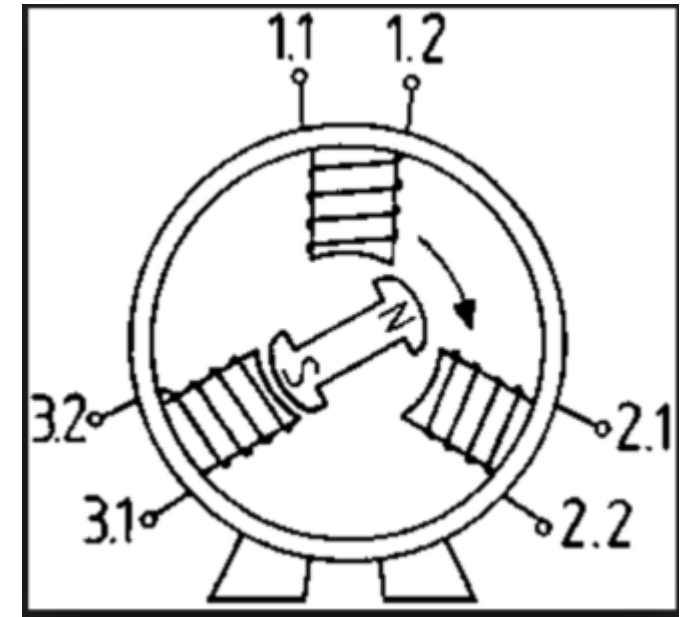
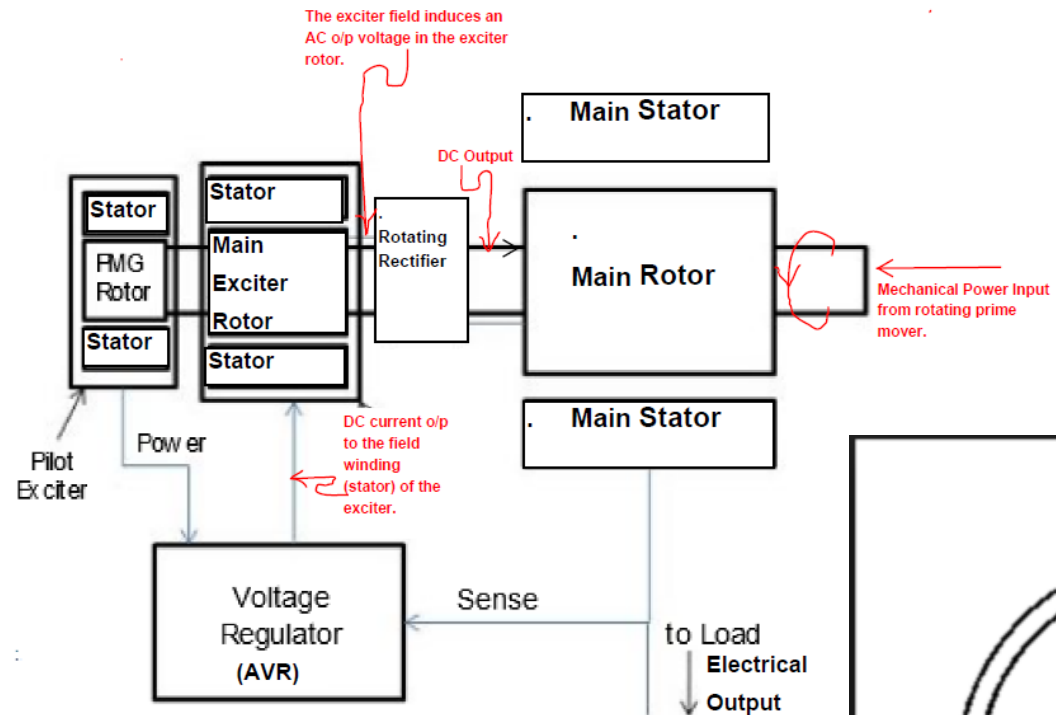
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# When an alternator is subjected to the Leading PF loads!

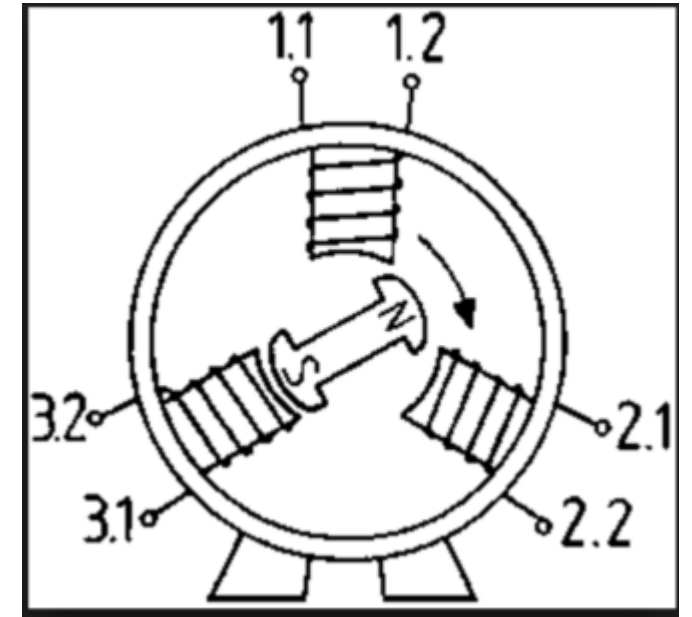
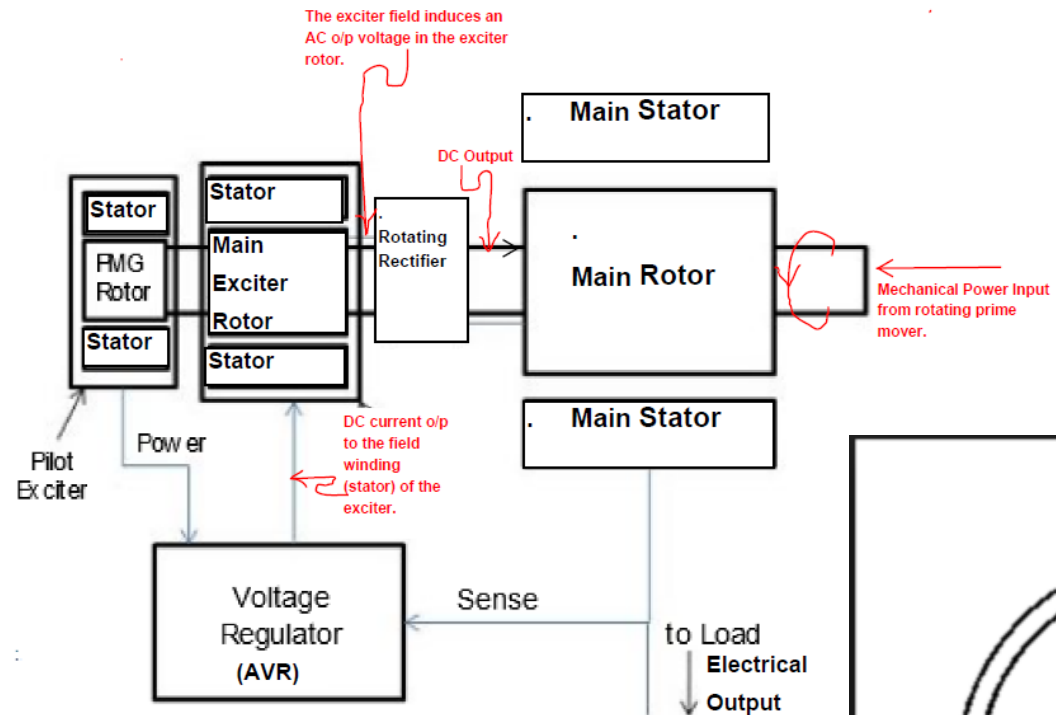
- Unity PF Load → Main Rotor winding field strength is determined solely by the excitation current that is controlled by the AVR.
- Reactive PF Load → Out of phase component in the load current → induces out of phase magnetic field in the main rotor → may strengthen or weaken the main rotor magnetic field.
- For example: Lagging out of phase component of the load current → partially cancels the main rotor magnetic field → AVR must increase its excitation to compensate.





# When an alternator is subjected to the Leading PF loads!

- For example: Leading out of phase component of the load current → tends to strengthen the main rotor magnetic field → Stator output voltage rises → AVR must reduce its excitation to compensate. i.e. regulate the voltage.
- This leading out of phase current component produces reverse KVAR.
- If the leading PF load keeps on increasing → increases reverse KVAR → continues to boost the main rotor magnetic field → AVR continues to reduce excitation



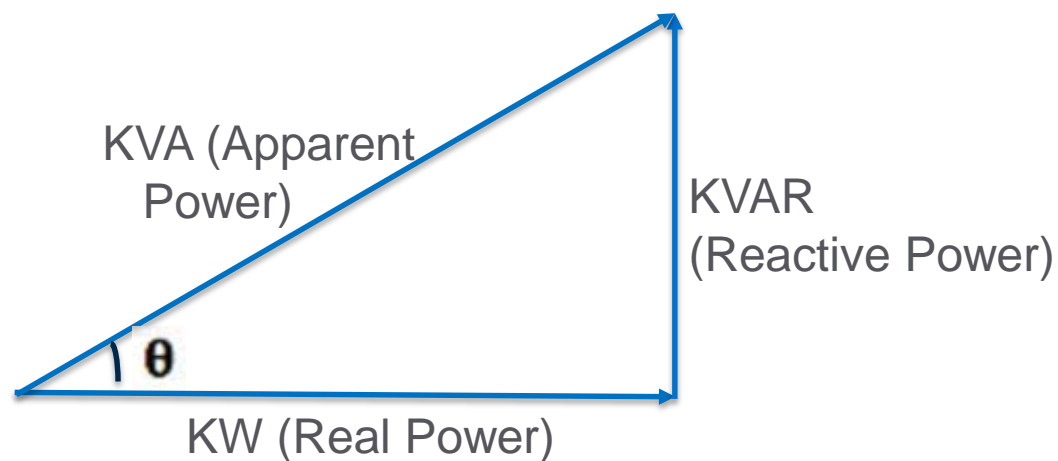


**How do you know how much Reverse KVAR or the leading out of phase current can be withstood by an alternator?**

**We never ask this question to the utility company (!)**

# Power Triangle

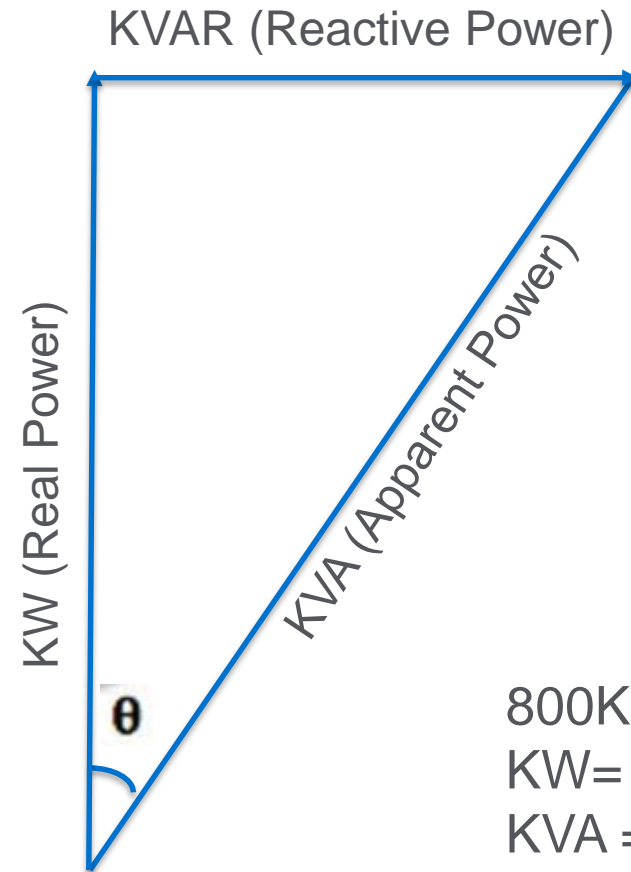
## Power Triangle



## Power Factor

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# Alternator Capability Curve



## Example:

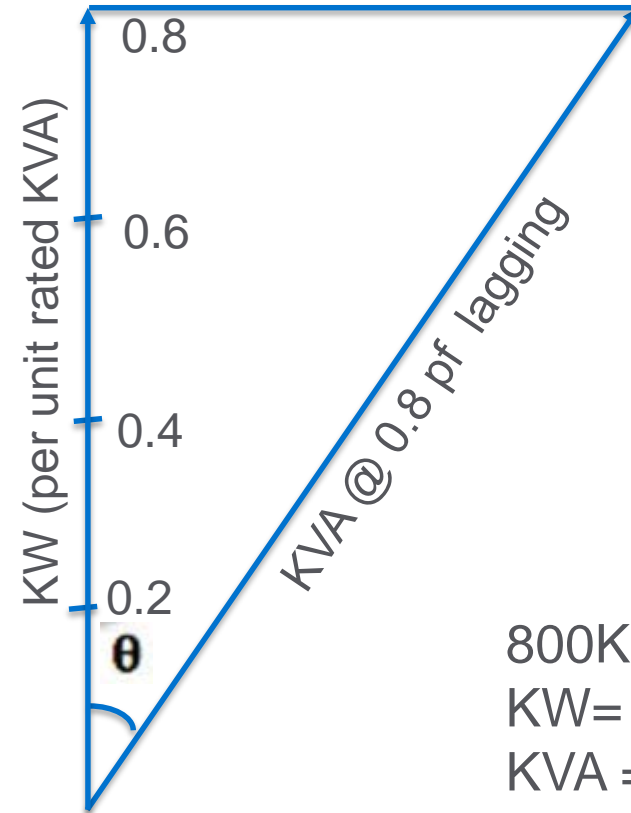
800KW GenSet at 0.8pf lagging

KW = 800

KVA = 1000

KVAR = 600

# Alternator Capability Curve



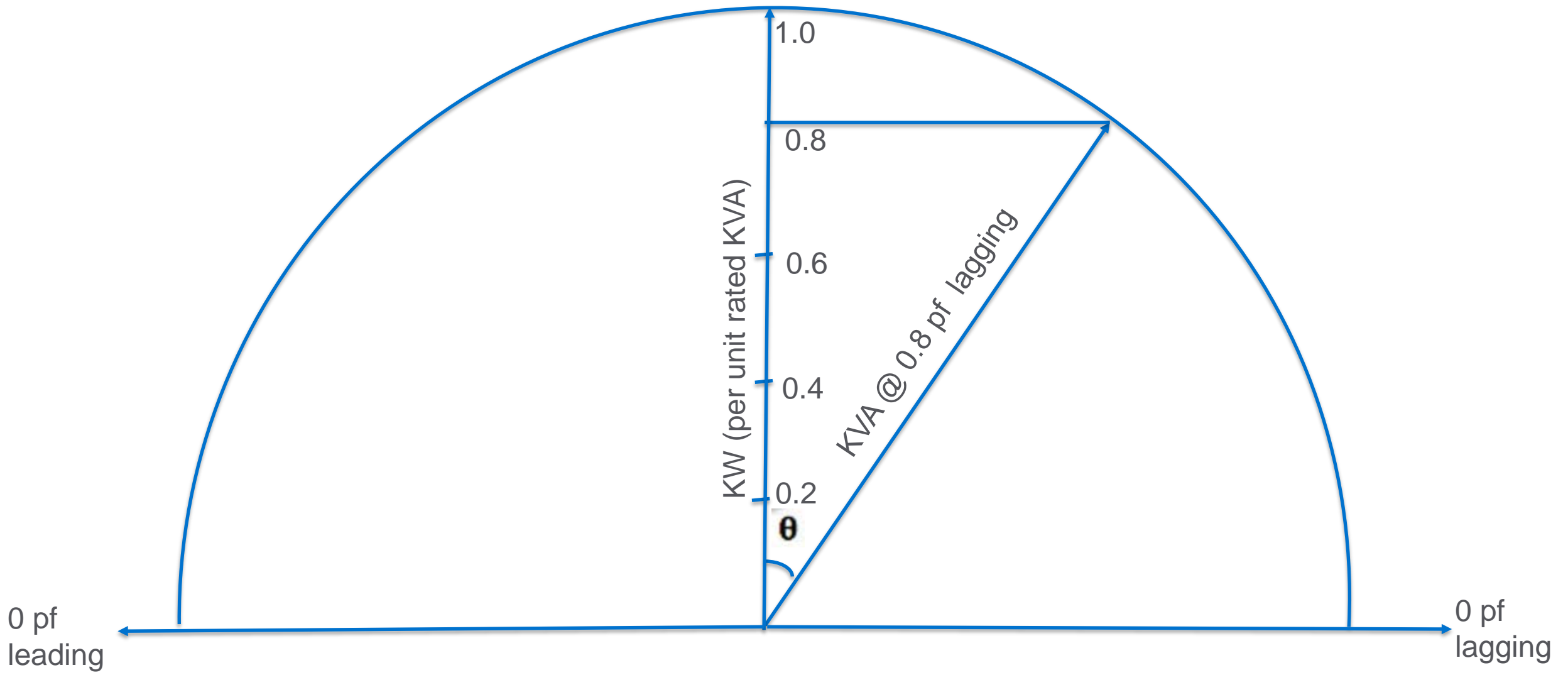
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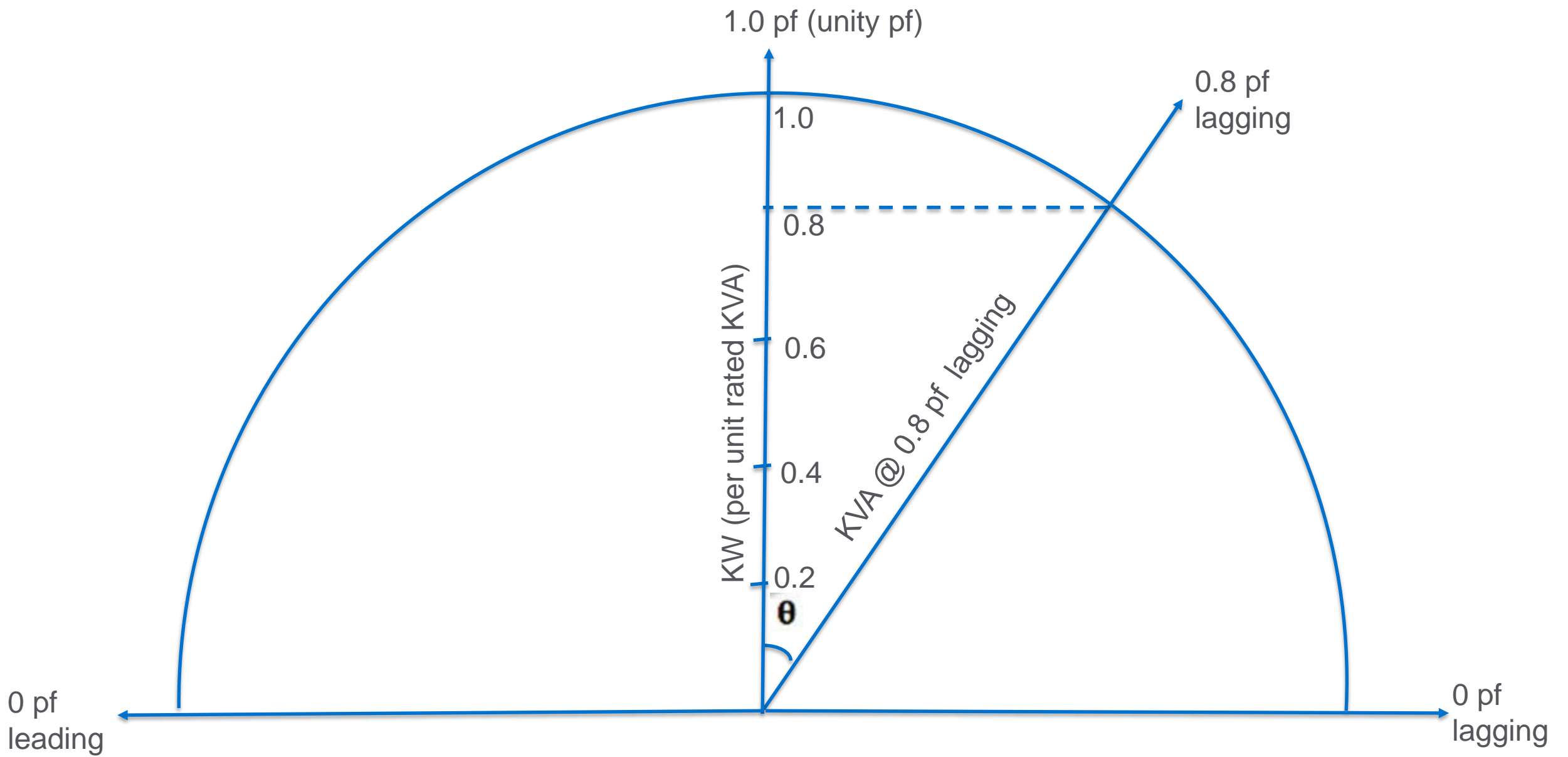
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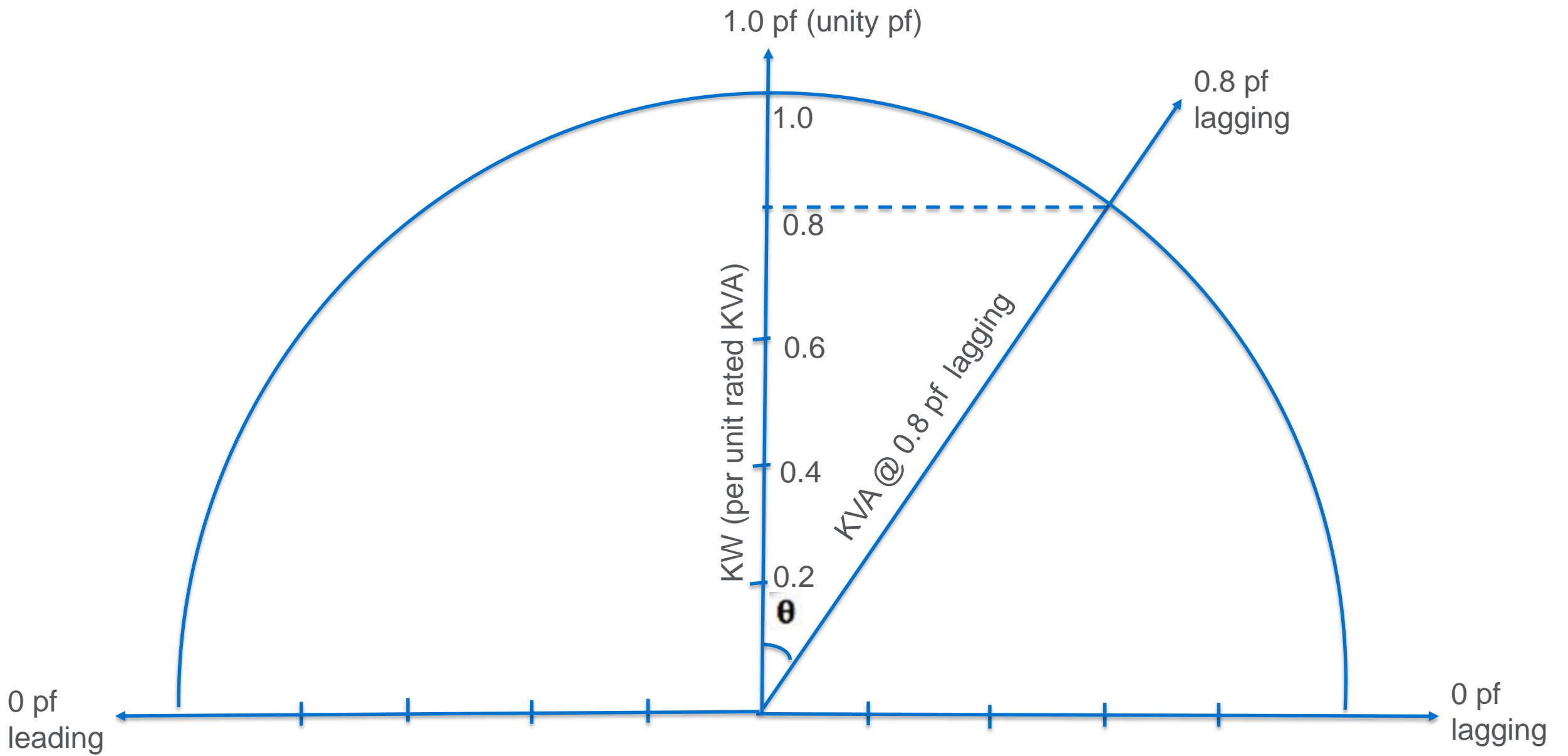
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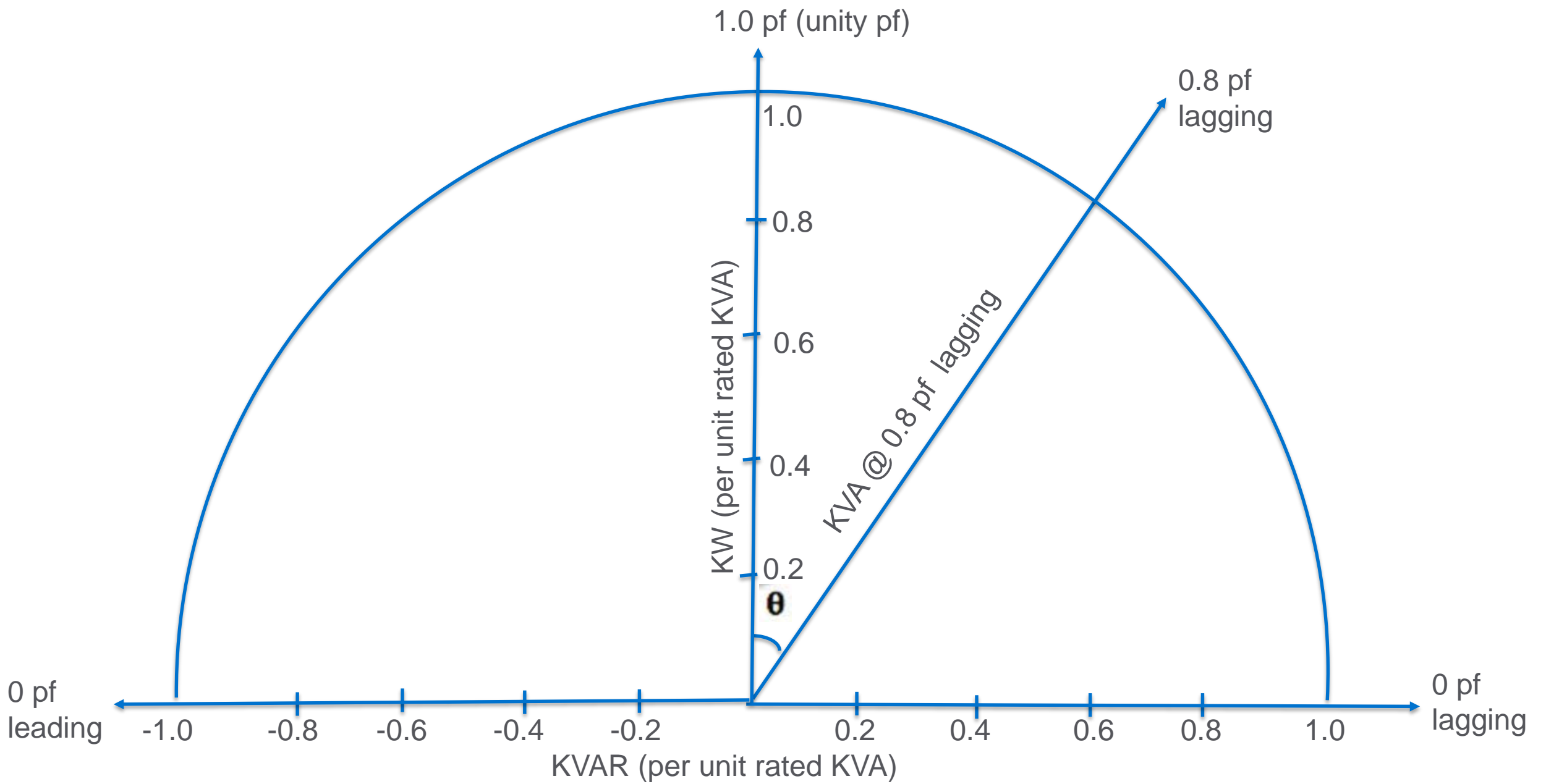
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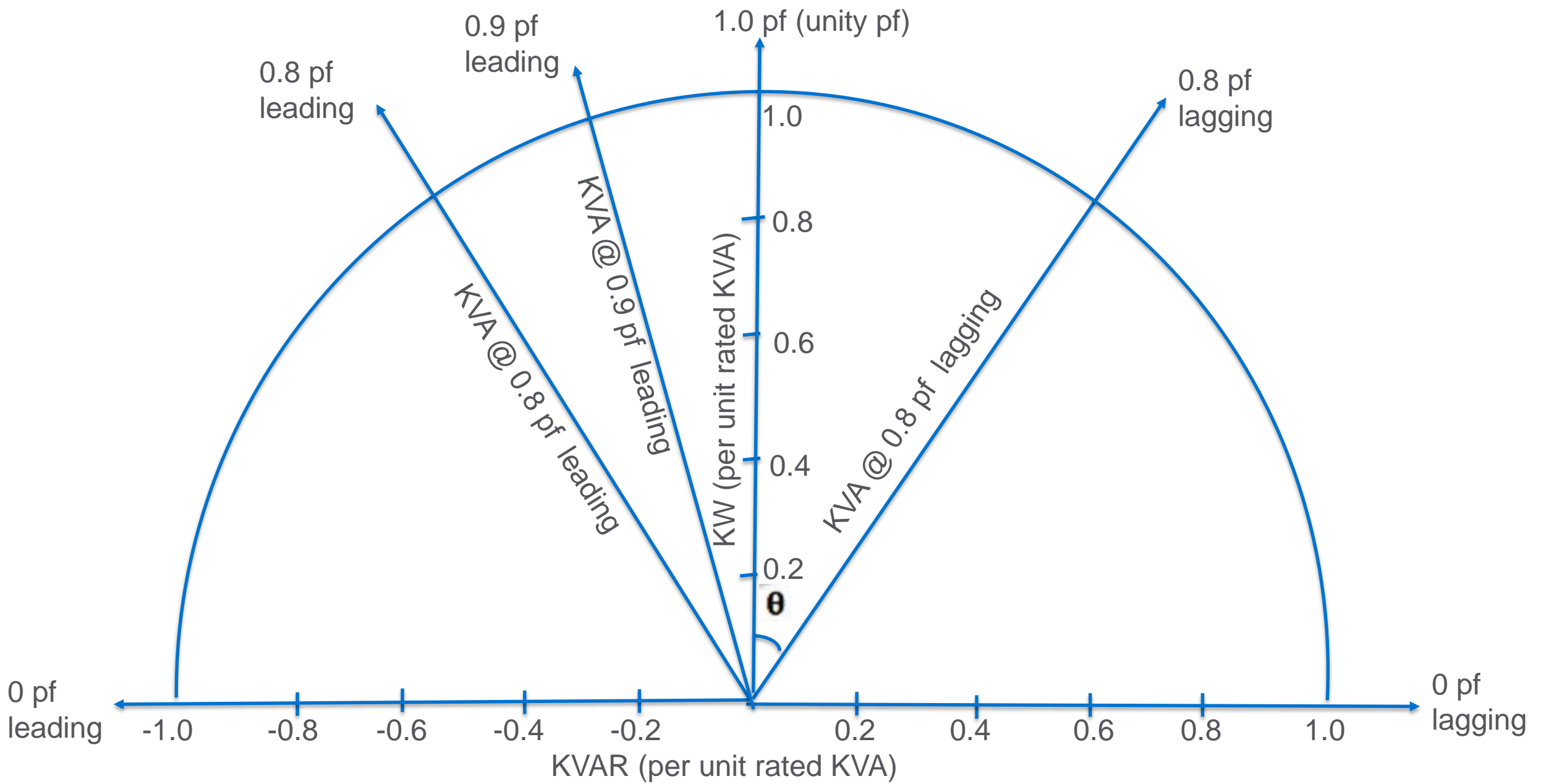


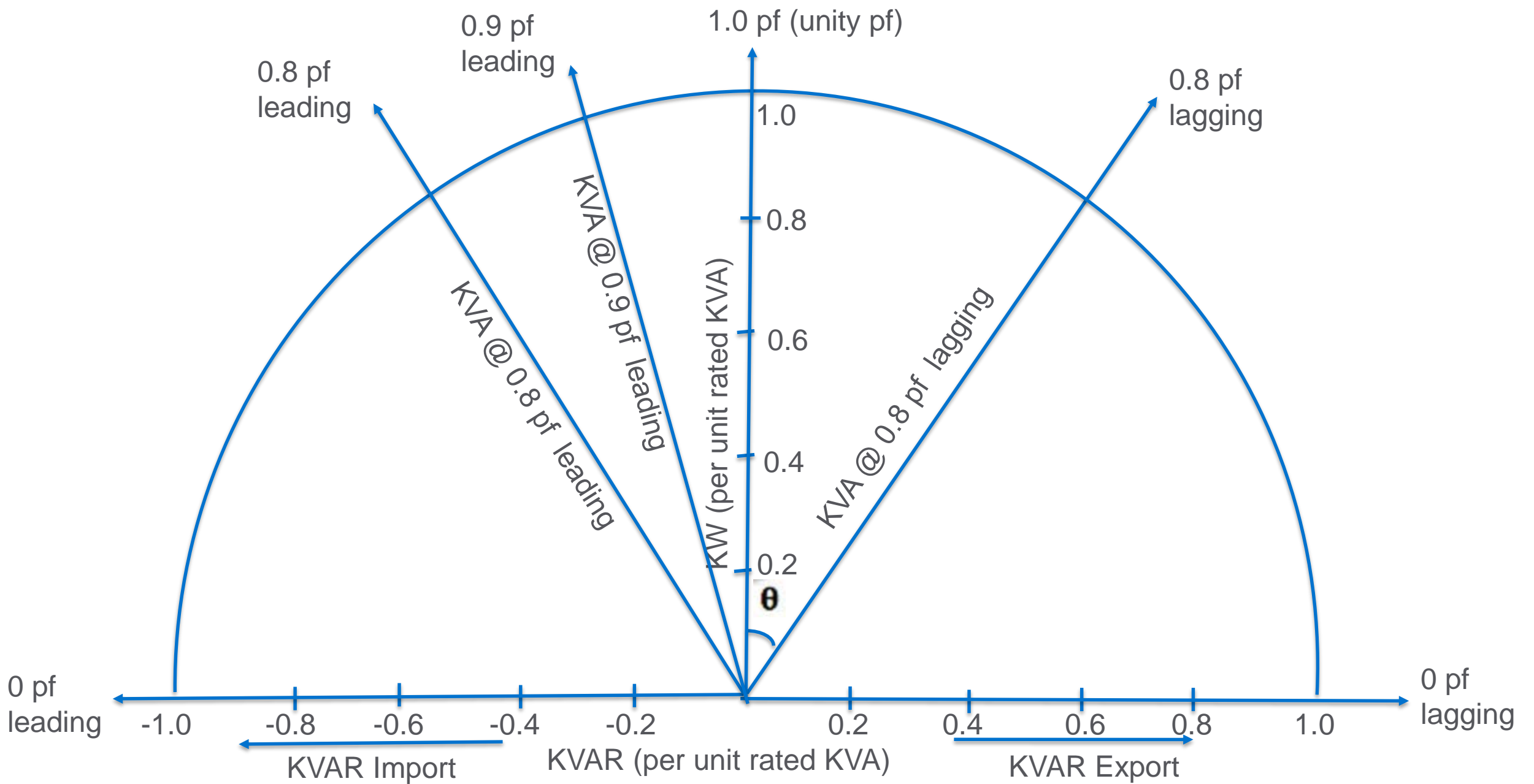




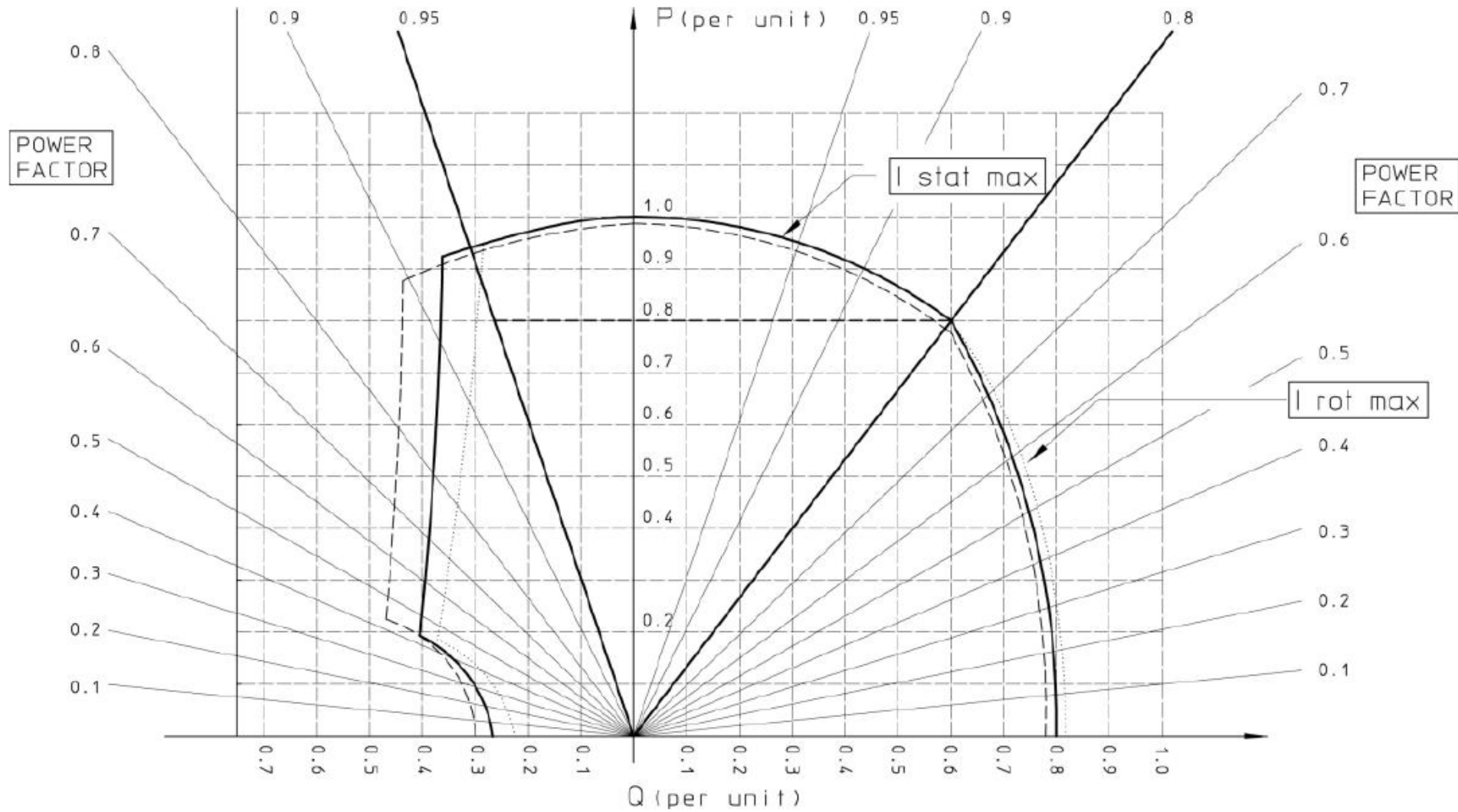


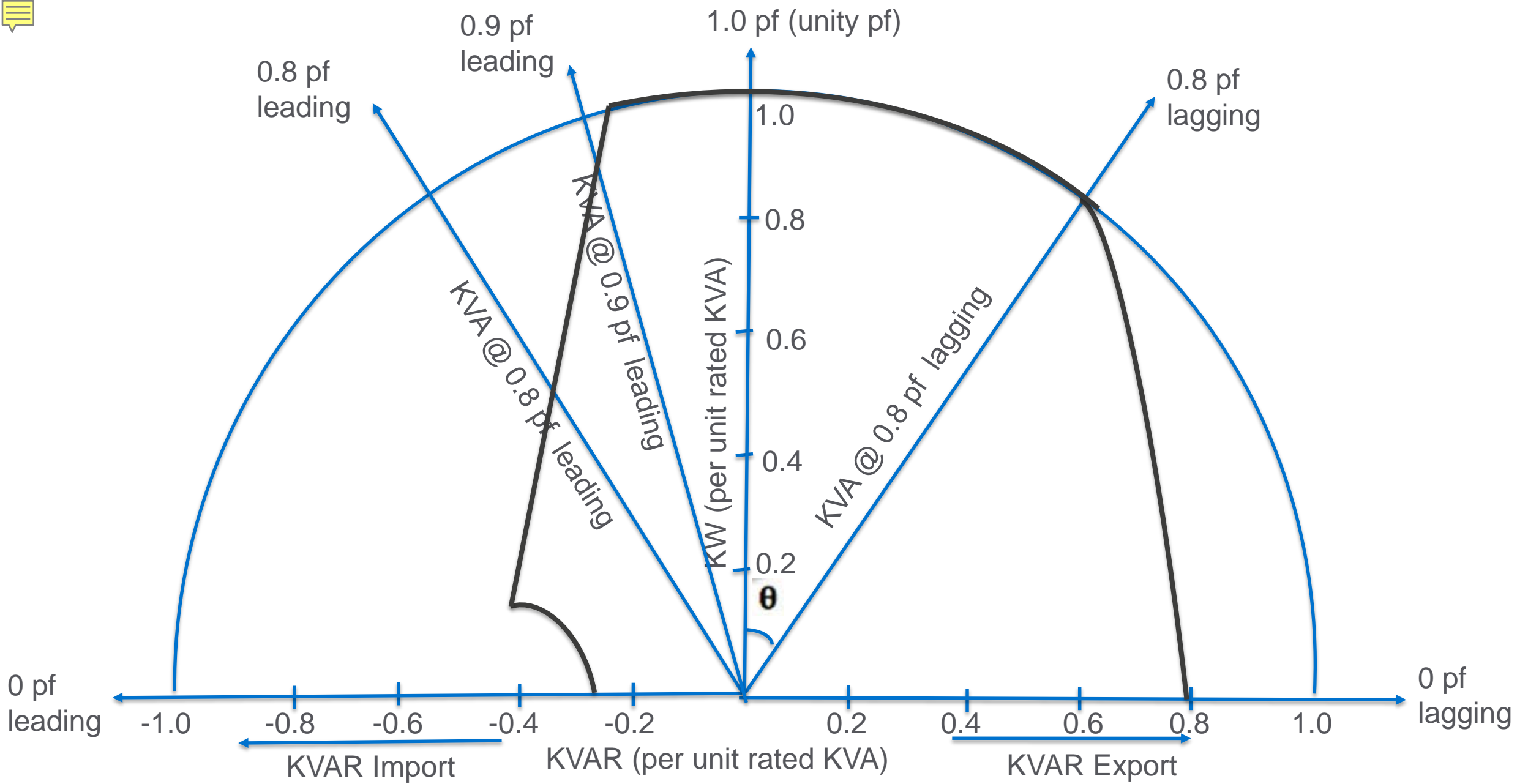


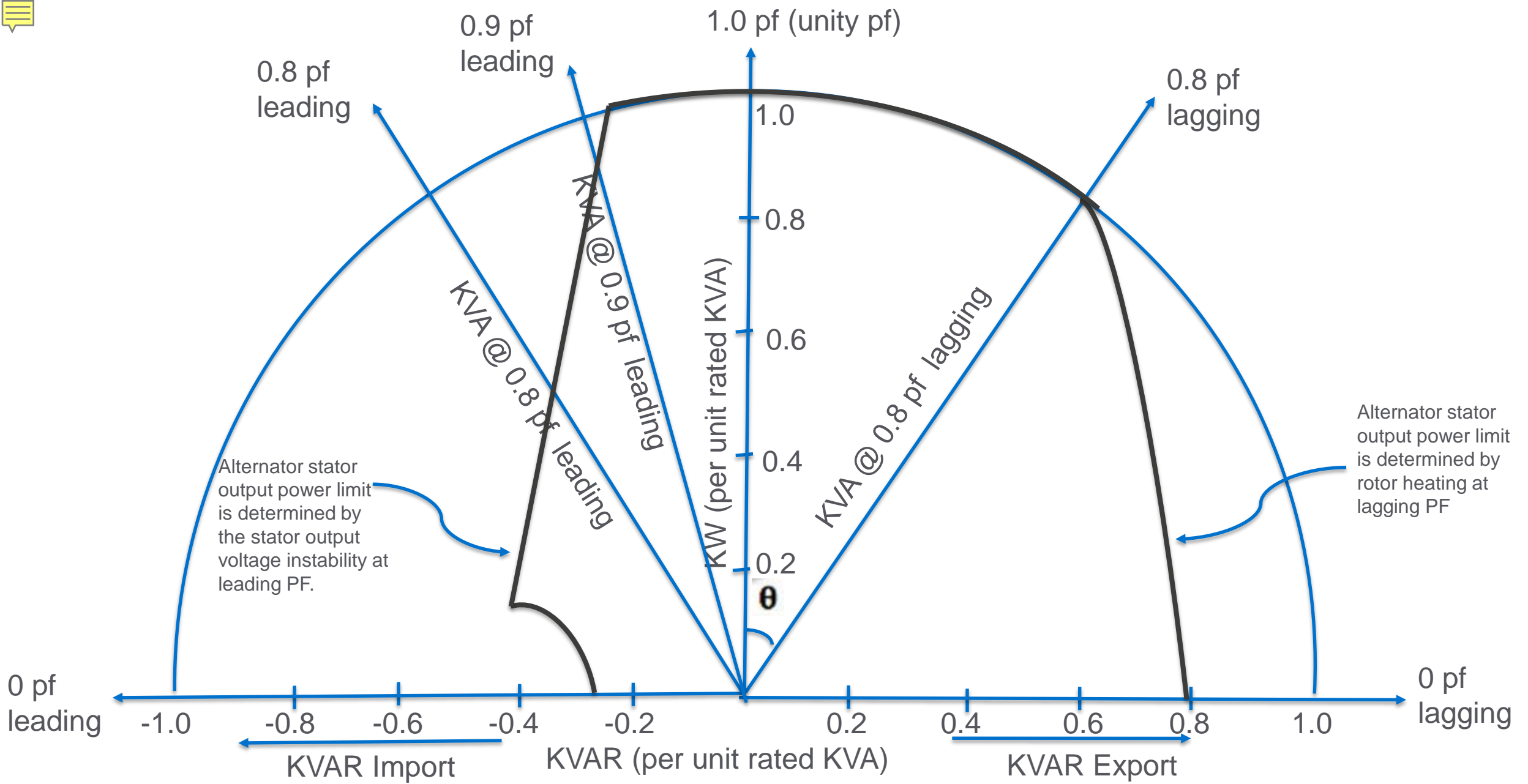


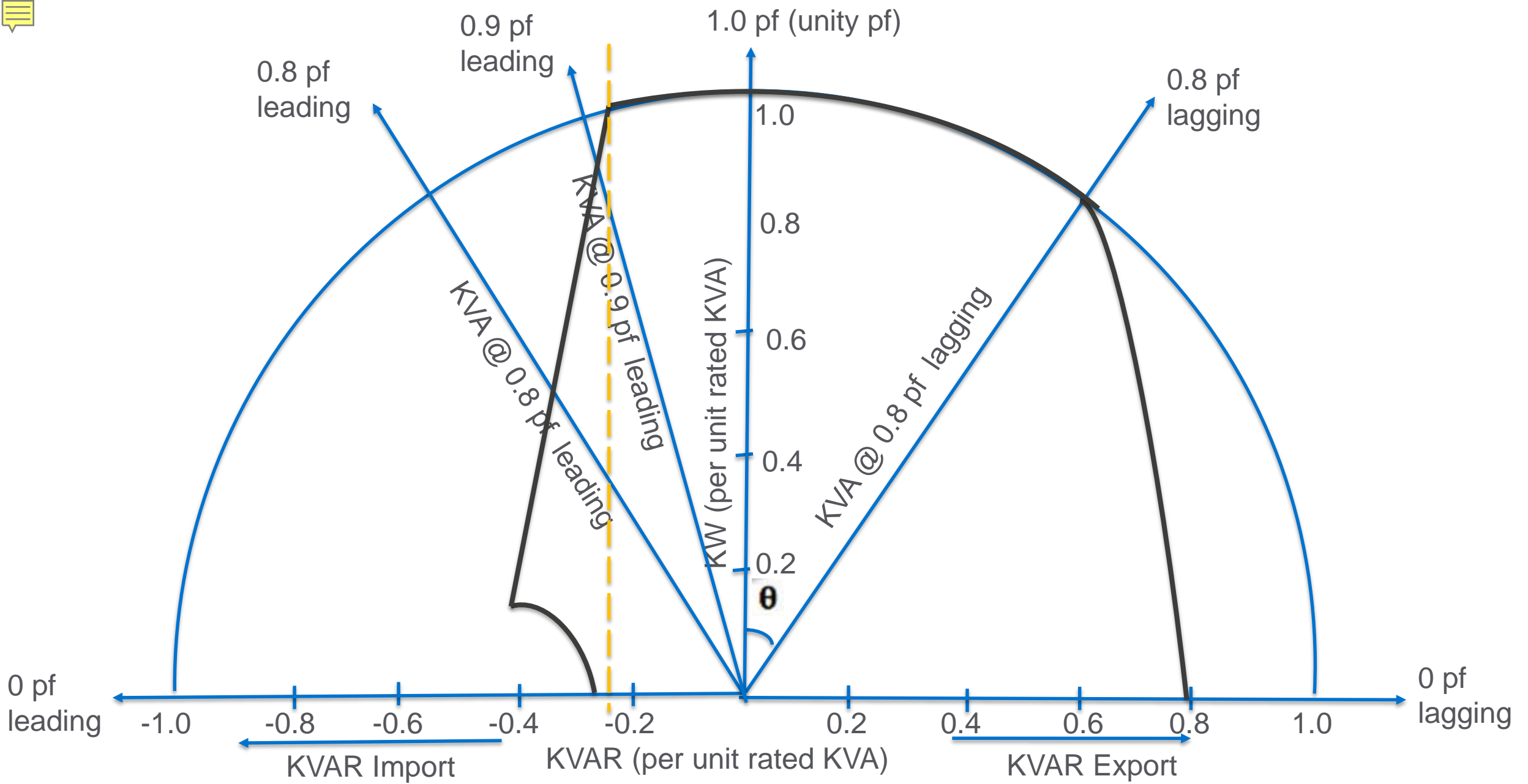


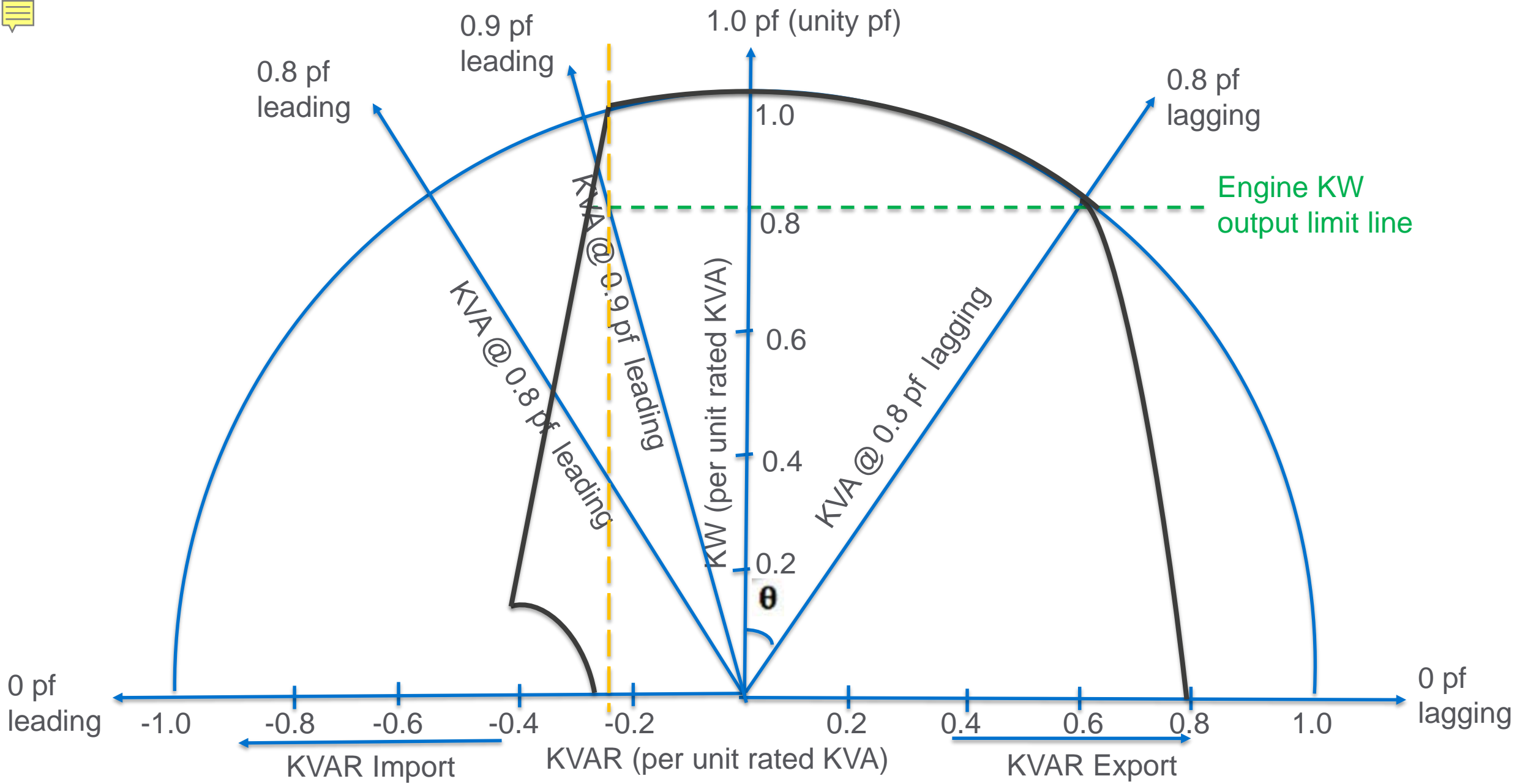
# Alternator Capability Curve – sample diagram



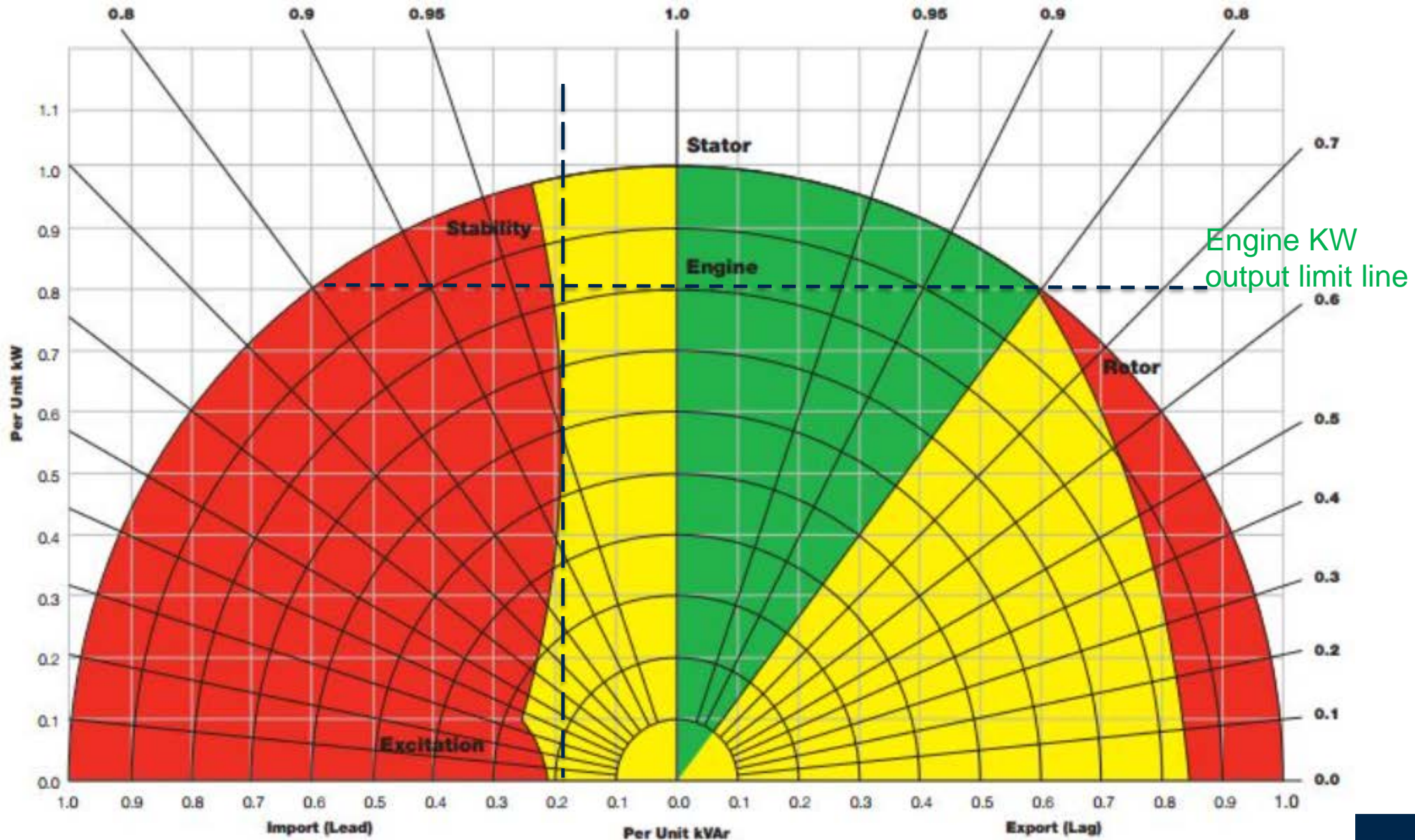






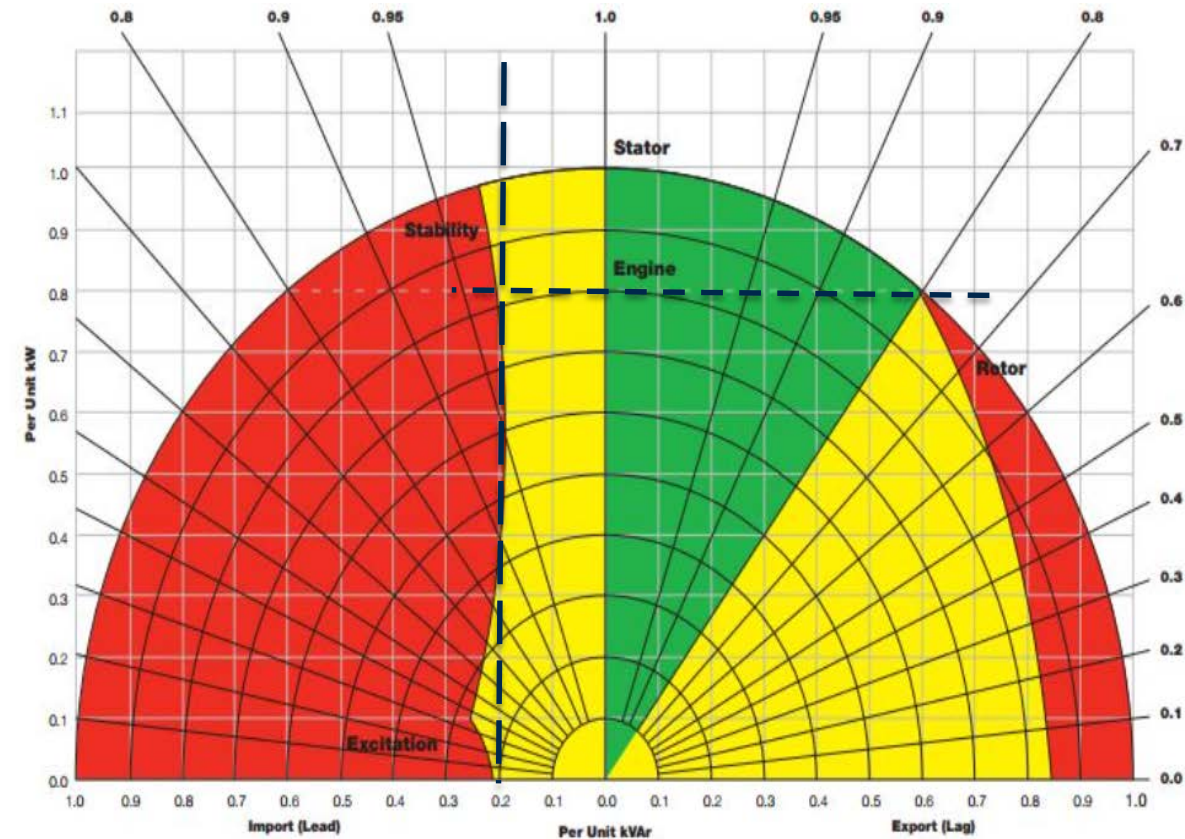






# When an alternator is subjected to the Leading PF loads! - Summary

- Reverse KVAR (Leading out of phase current component)
- Stator output voltage rises
- AVR decreases the excitation
- Too much reverse KVAR can cause the AVR completely turn off and lose control
- The voltage overshoots uncontrollably
- Result:
  - The generator shuts down
  - Damage to the loads
  - The UPS goes into the by-pass mode or switches to the battery





# Facts to Remember

- Loads with the Leading out of phase current component (leading power factor) produce reverse KVAR
- The alternator has limited capability of absorbing the reverse KVAR
- A blanket statement: The KVAR absorption capability of an alternator is XYZ irrespective of the leading power factor value of the load.
- The KVAR absorption capabilities of alternators are different amongst the manufacturers.
- The harmonics limiting filters, when sized to the rated capacity of the UPS can cause leading power factor on the power source.
  - Lightly loaded UPS
  - UPS ramping up from no load



# Recommendations: Open to discussion

- The expected reverse KVAR from the load should be calculated in the design phase of the project.
  - The leading PF value is not important!
  - Alternator Capability curve in the submittal package
- Specify lower temperature rise Alternator (larger KVA)
  - Lower sub transient reactance
- While loading a GenSet, care should be taken to not generate reverse KVAR to the unacceptable level.
  - Add inductive loads first
  - Add inductive loads along with the leading PF loads in smaller steps
- While on the GenSet, turn off or limit the operation of the UPS filters until other types of loads are connected.
  - If acceptable by other loads
  - Today's advance excitation systems and other contemporary features on the GenSet contribute to provide stable voltage as well

# KOHLER Power Systems



## TOTAL SYSTEM INTEGRATION

GENERATORS | TRANSFER SWITCHES | SWITCHGEAR | CONTROLS