POWER ENGINEERING
#17 SYNCHRONOUS GENERATORS (II)

2016

University of Glasgow

Plan for Today:

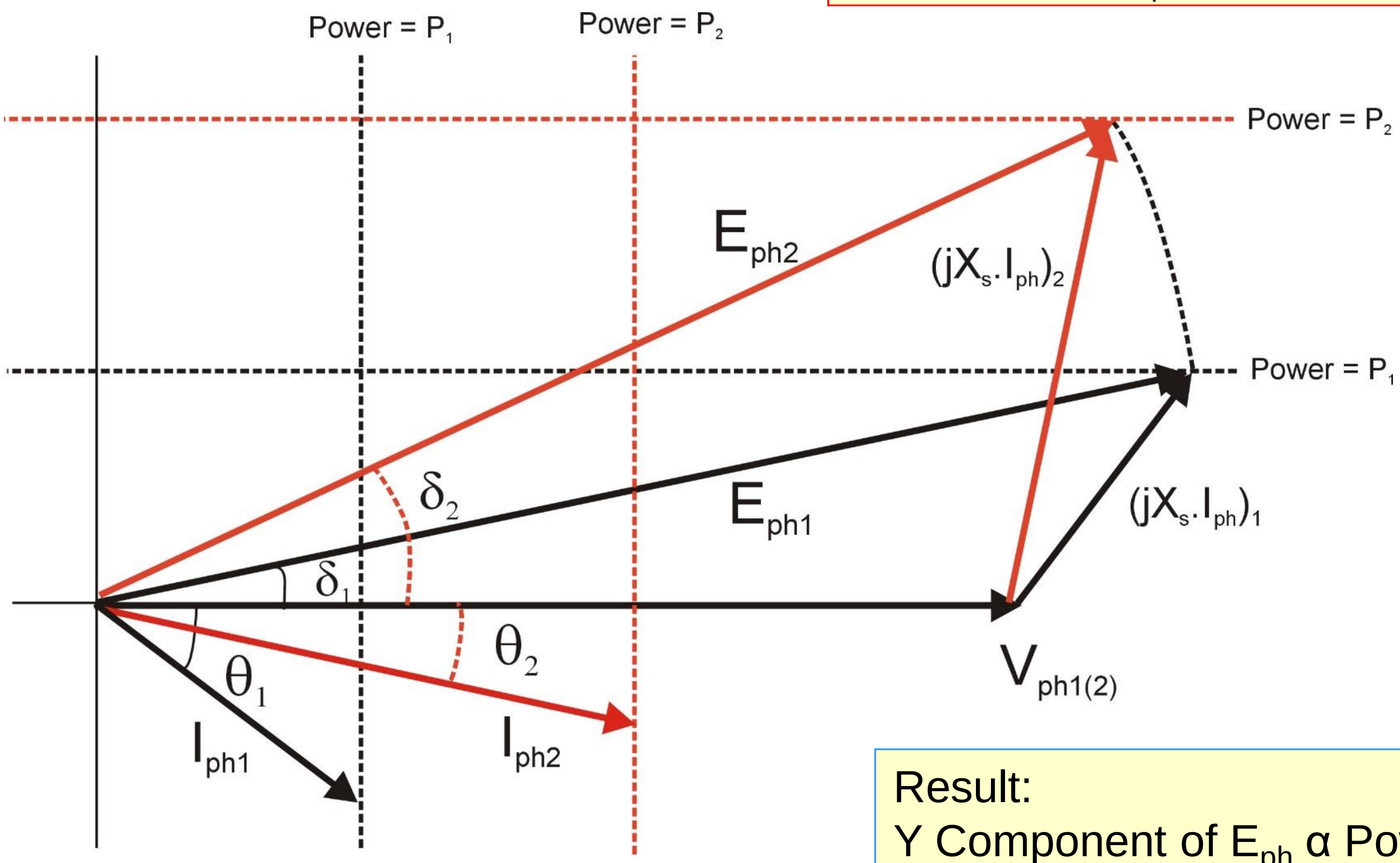
- Quick recap on Power Lines on Phasor Diagram
- Example
- Grid Connected Generator Summary:
  - Changes to Load
  - Changes to Excitation Voltage
- Operating Limits of a Synchronous Generator

Grid Connected Generator: **Example**

x2 increase in Output Power (W):

Procedure:

1. E_{ph} rotates CCW to P_2 line
2. Calculate V_{xs}
3. Calculate I_{ph}



Result:
Y Component of E_{ph} α Power
X Component of I_{ph} α Power

Lecture 16 Example:

Part A

A 3 phase Synchronous Generator with a Synchronous Reactance of 25Ω is connected to an 10kV (Phase Voltage) grid and supplies 1MW at a 0.819 lagging Power Factor at its terminals. Calculate the phase current and resultant V_{XS}, and from the phasor diagram graphically determine the required Excitation Voltage (E_{ph}) and Load Angle (δ)

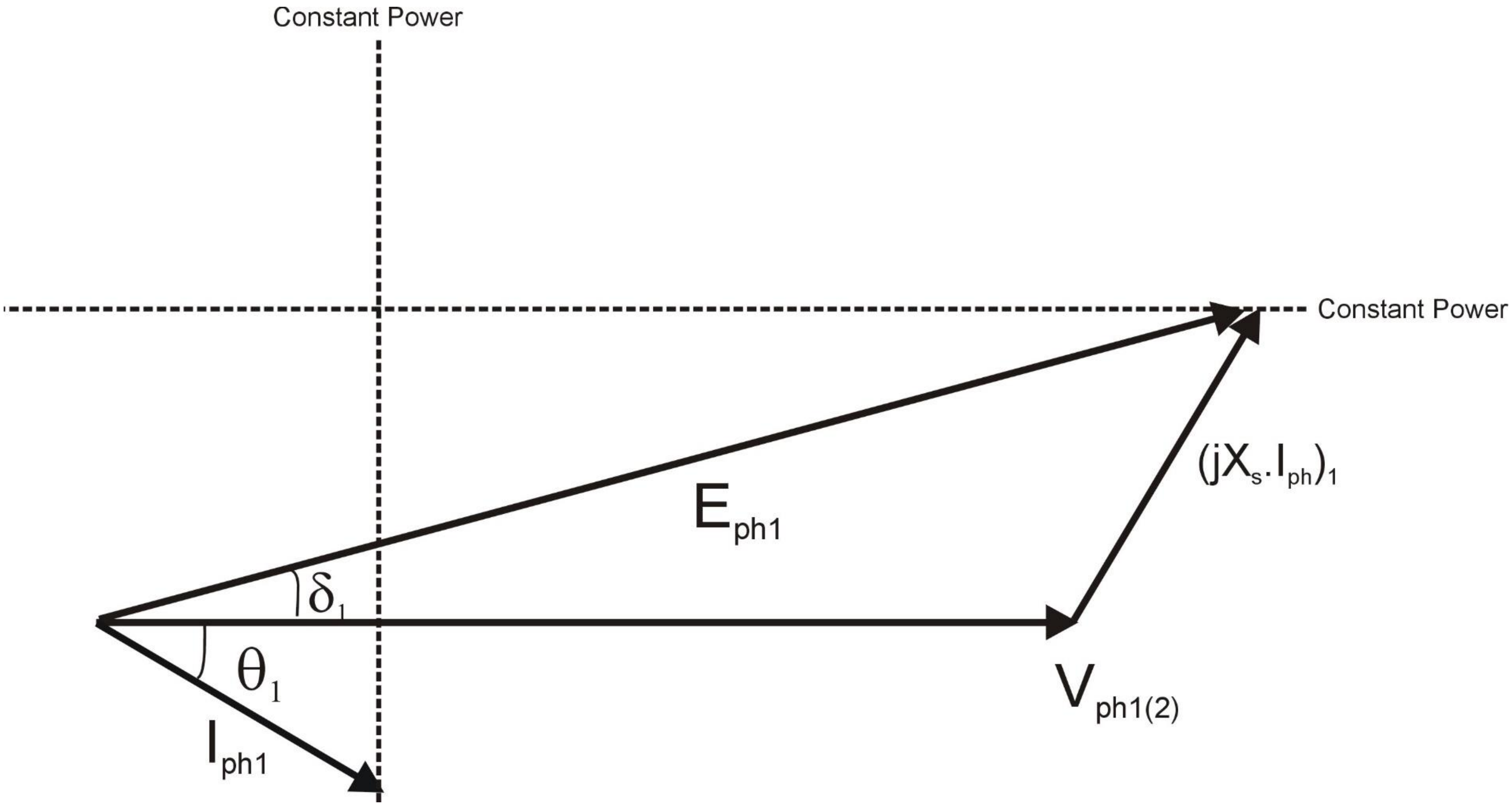
Part B

The load is increased to 3MW, calculate the resultant changes to the phase current, power factor and load angle for constant Excitation Voltage.

Solution done on whiteboard during lecture

Grid Connected Mode: Decrease in Excitation (E_{ph}), no change in Power

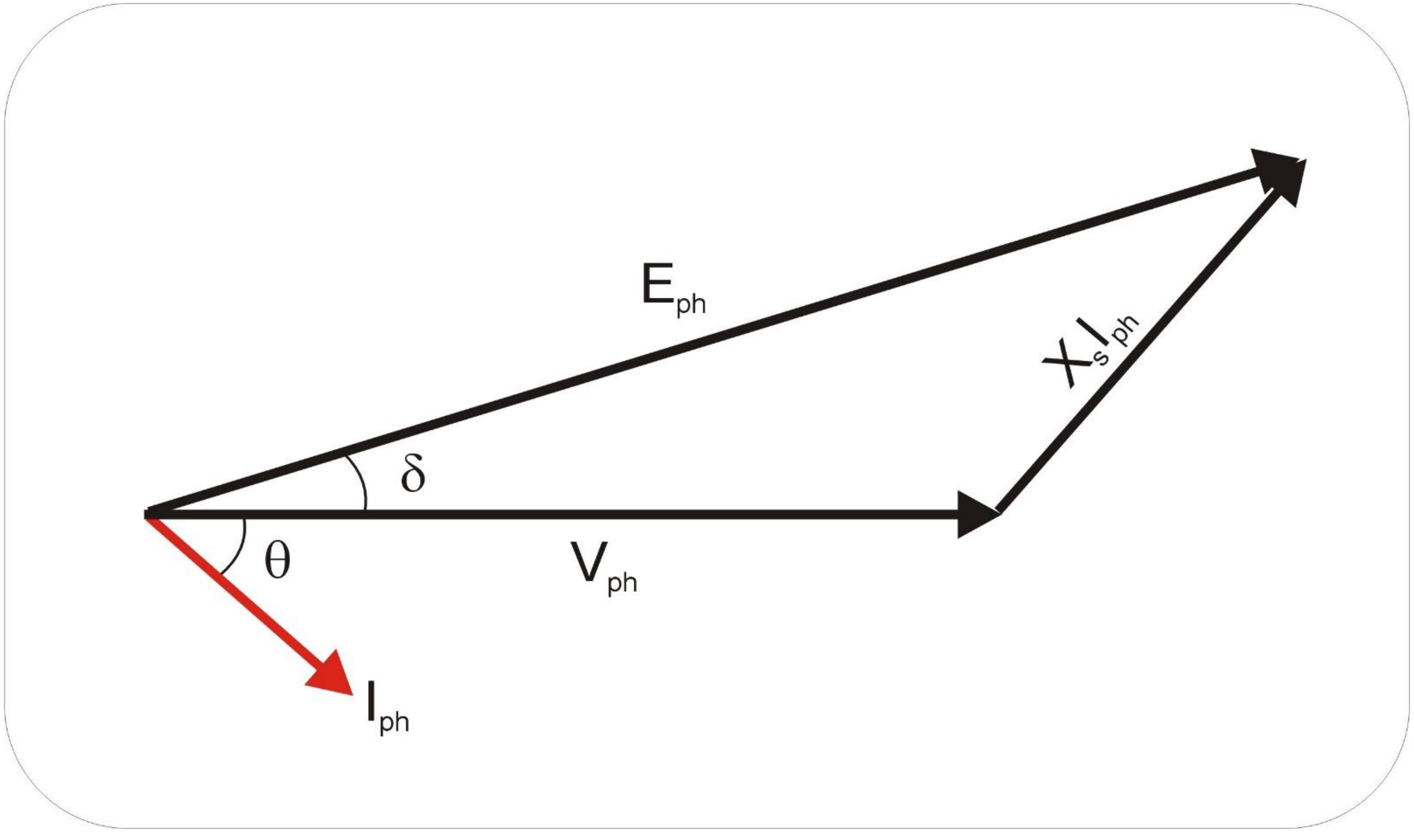
Fact: magnitude of Terminal Voltage (V_{ph}) is FIXED



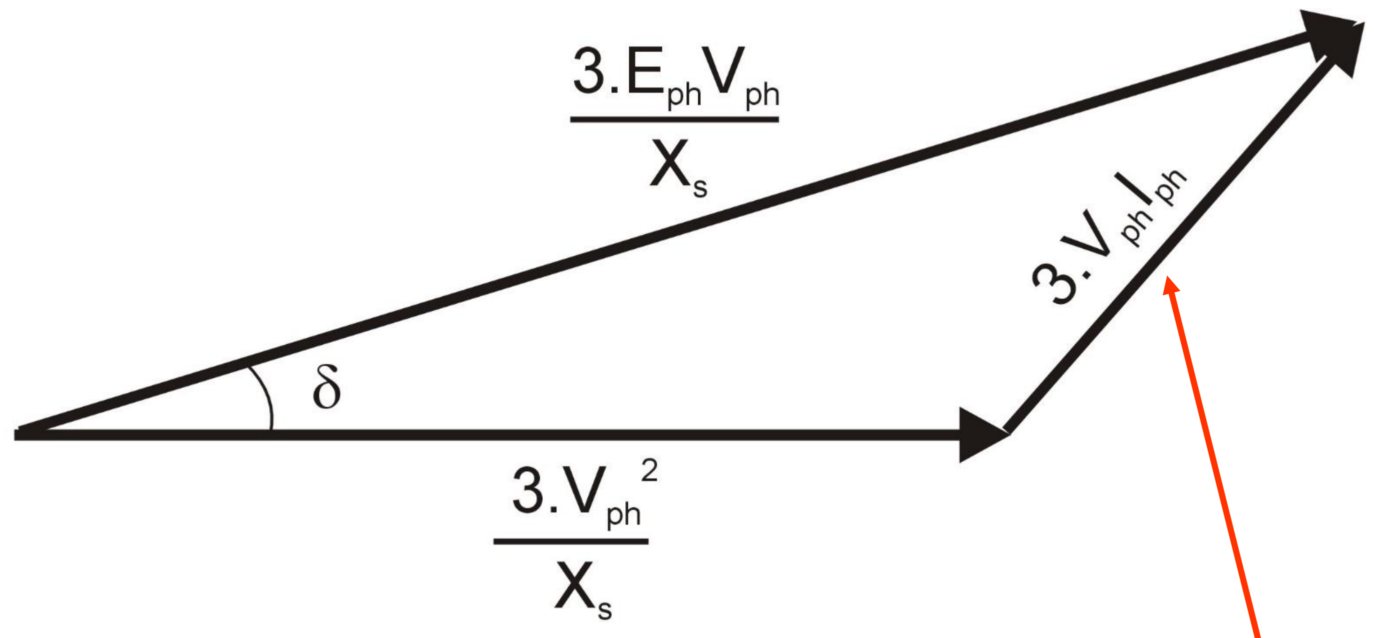
Results:

Synchronous Generator: Operating Limits

‘Typical’ Phasor Diagram:

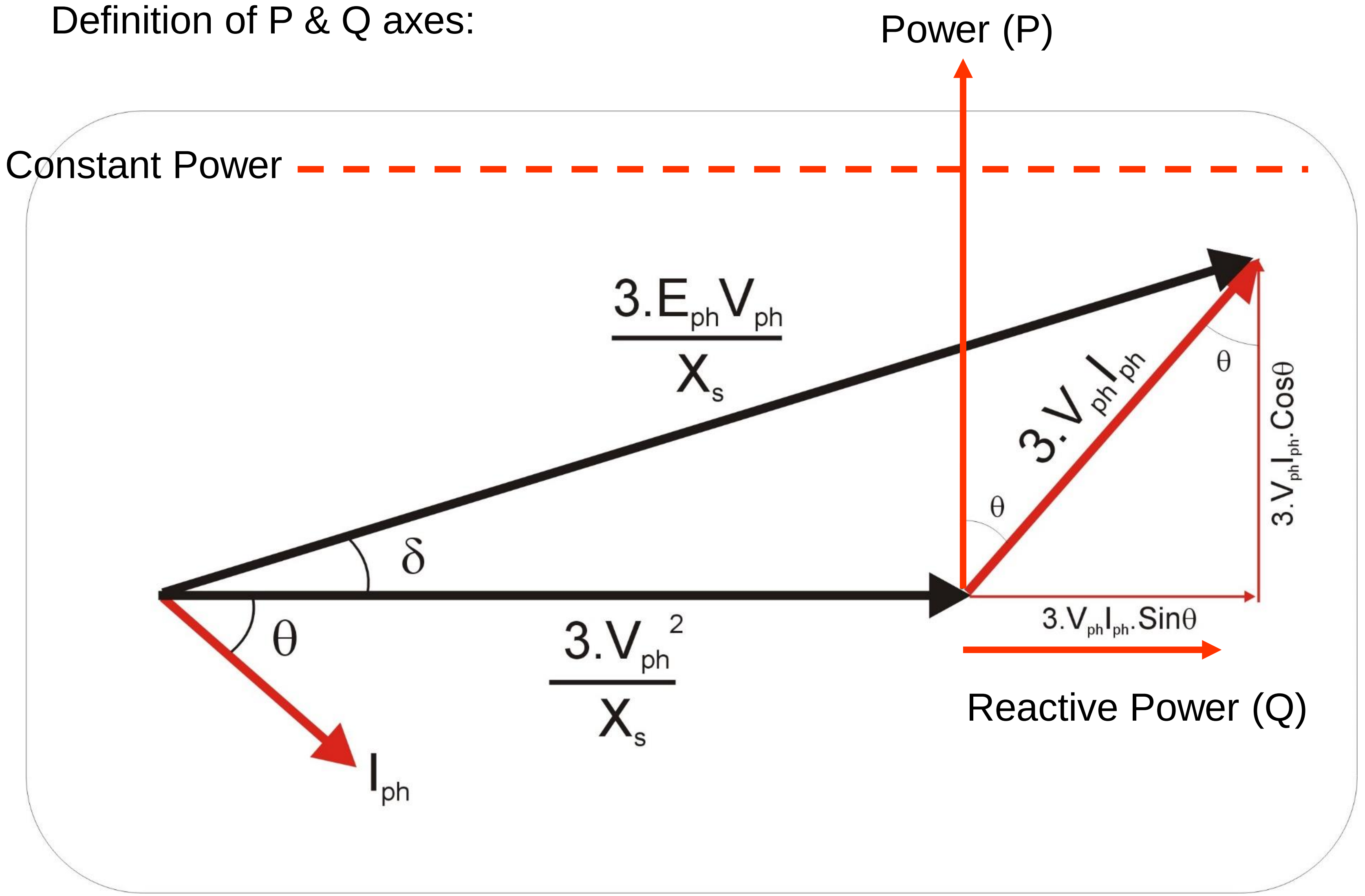


Multiply all Voltage Phasors by $3.V_{ph}/X_s$:



This phasor now represents Apparent Power (S)

Definition of P & Q axes:

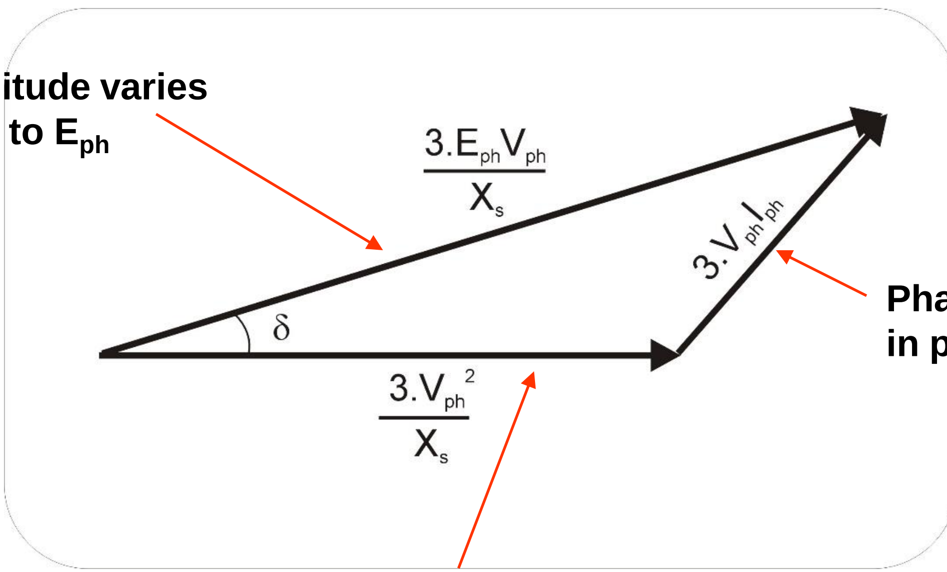


Generator Operation Constraints:

Assume connection to Grid (Infinite Bus) so V_{ph} remains constant throughout operation

Assume X_s remains constant throughout operation

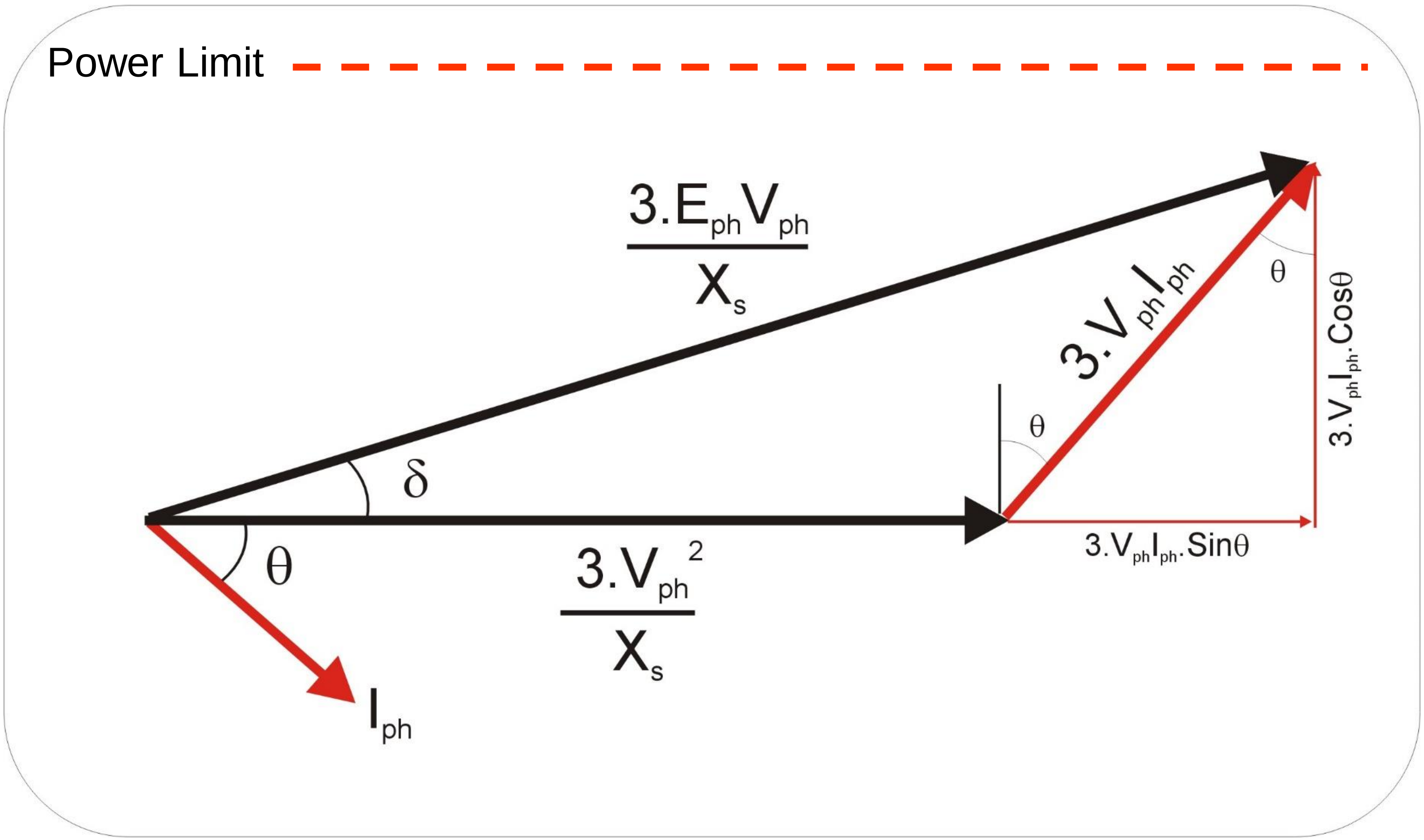
Phasor Magnitude varies in proportion to E_{ph}



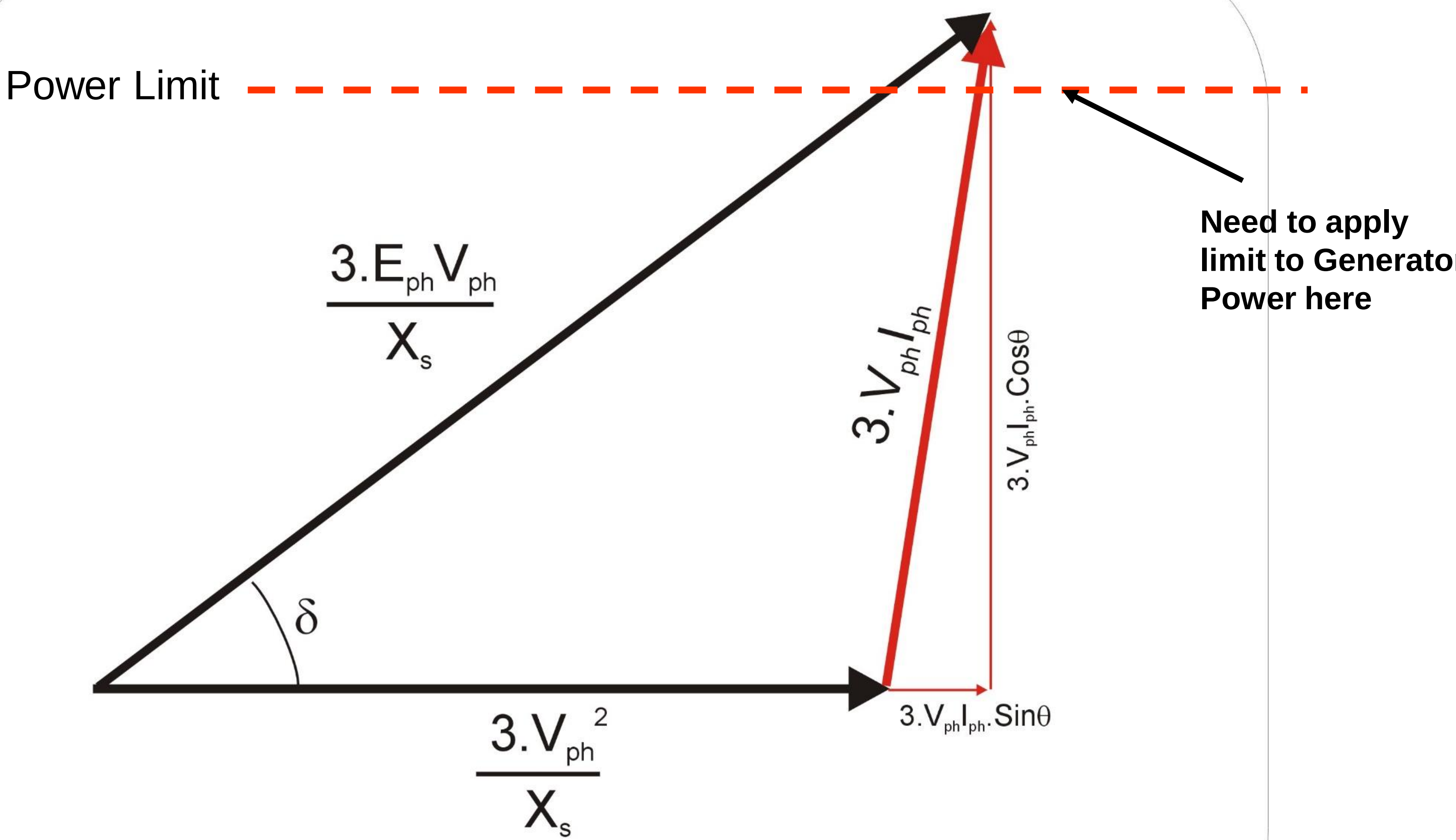
Phasor Magnitude varies in proportion to I_{ph}

Phasor is Constant

Operating Limit #1: Input (Prime Mover) Power



Generated Power < Input Power Limit **OK**

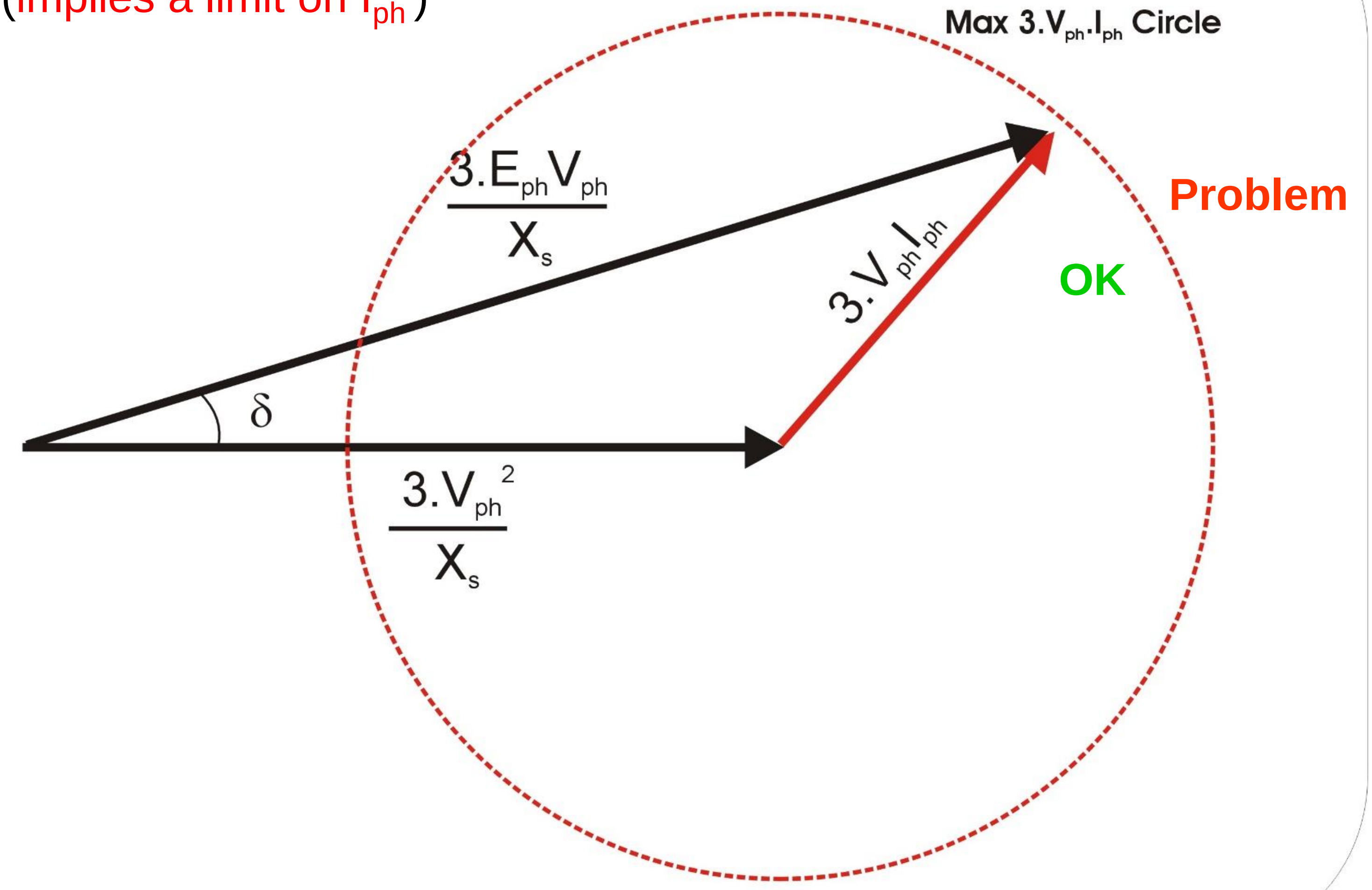


Generated Power > Input Power Limit

PROBLEM

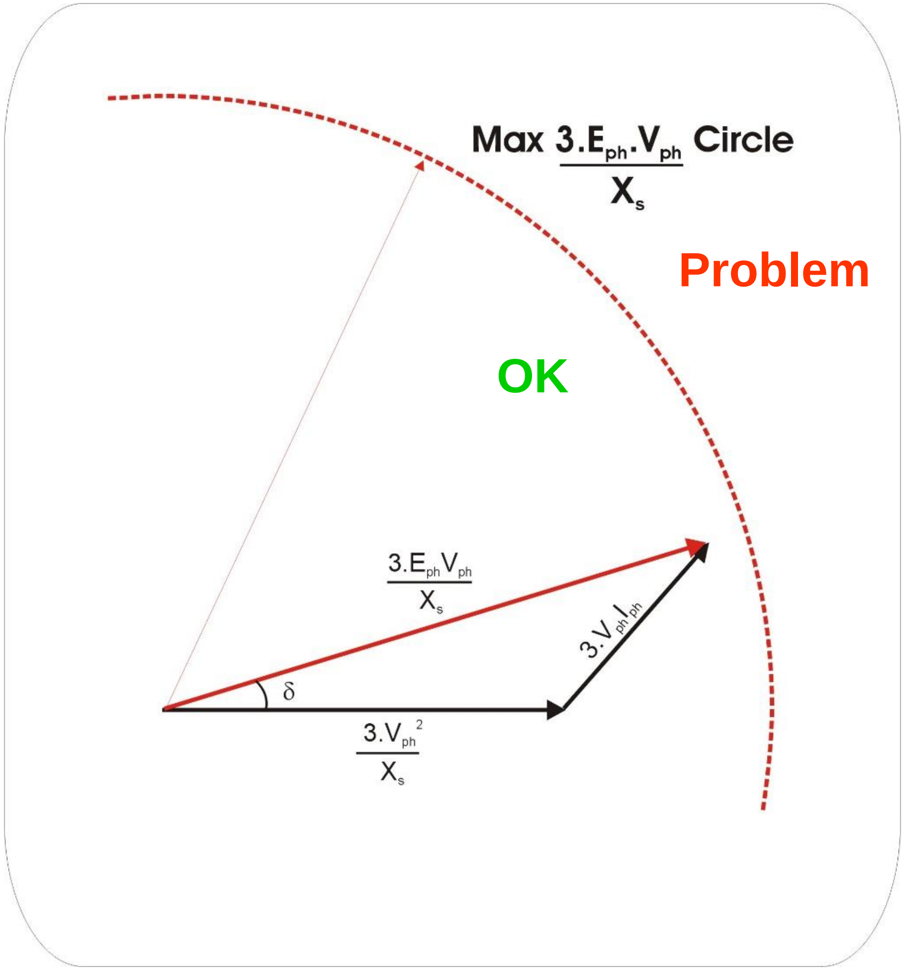
Operating Limit #2: Stator Copper Loss ($I_{ph}^2R_s$)

(implies a limit on I_{ph})



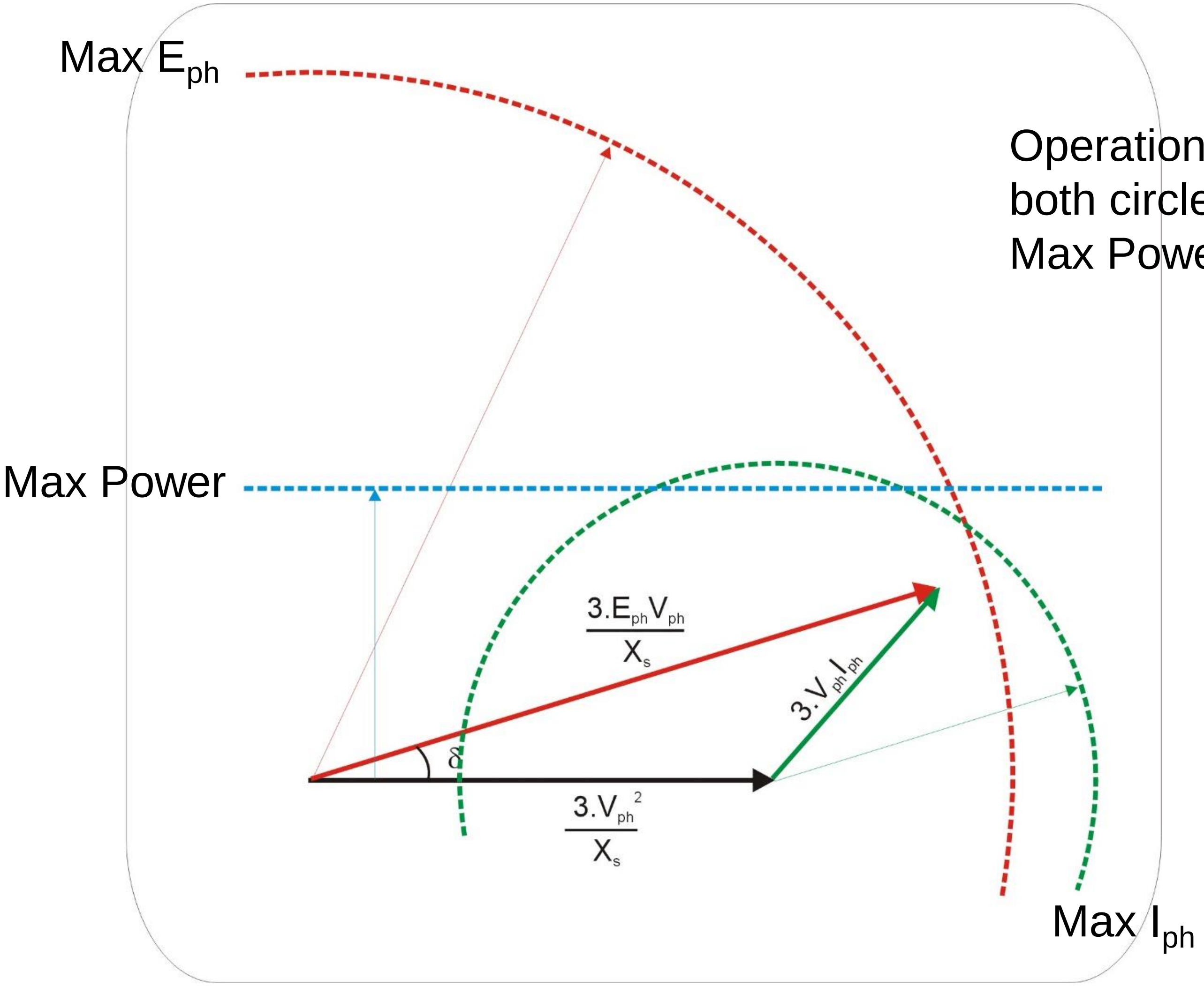
Operating Limit #3: Rotor Copper Loss ($I_f^2R_r$)

(implies a limit on E_{ph})



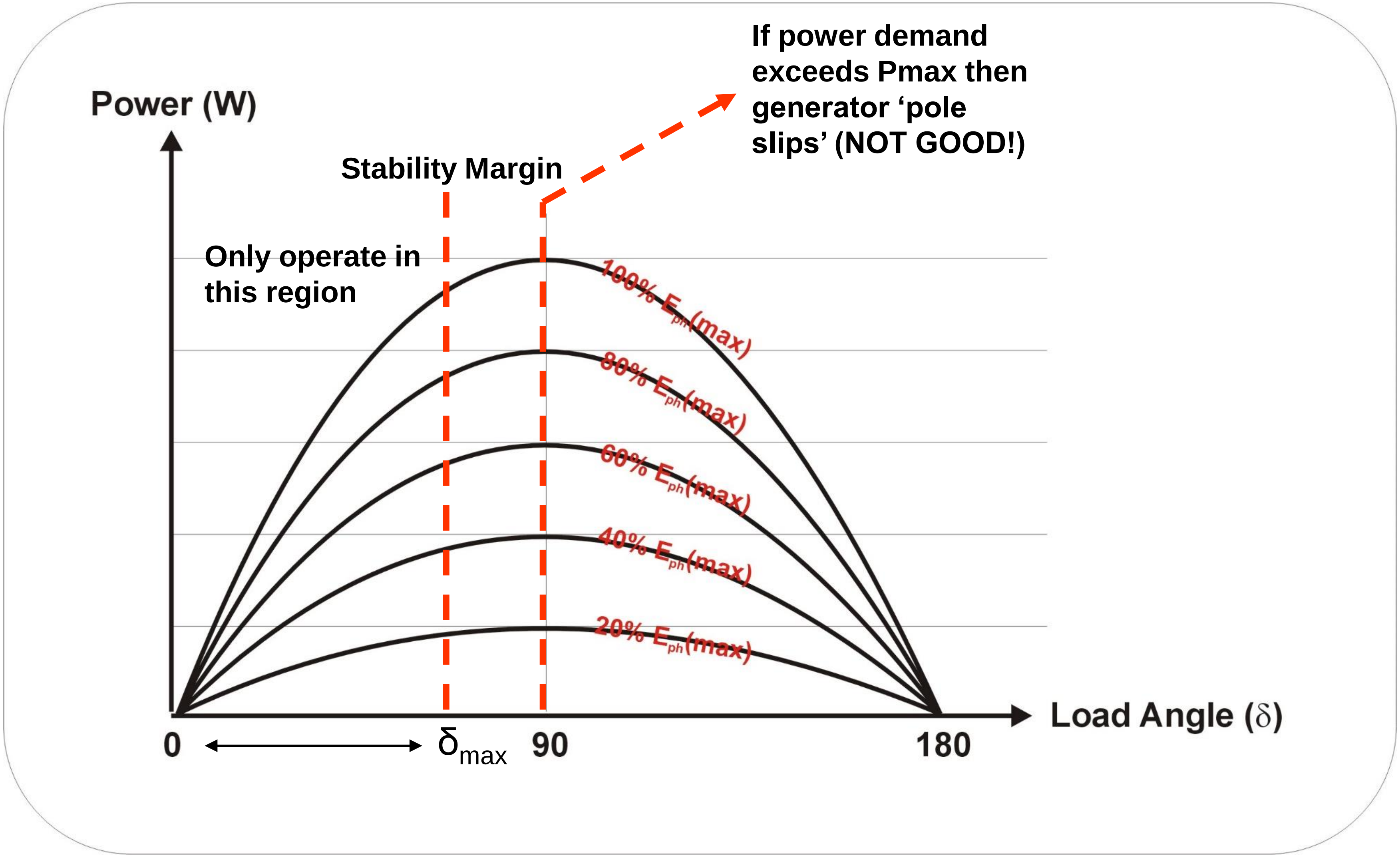
Note: magnetic saturation of stator & rotor may also limit I_f and E_{ph}

All limits shown on the same Phasor Diagram:

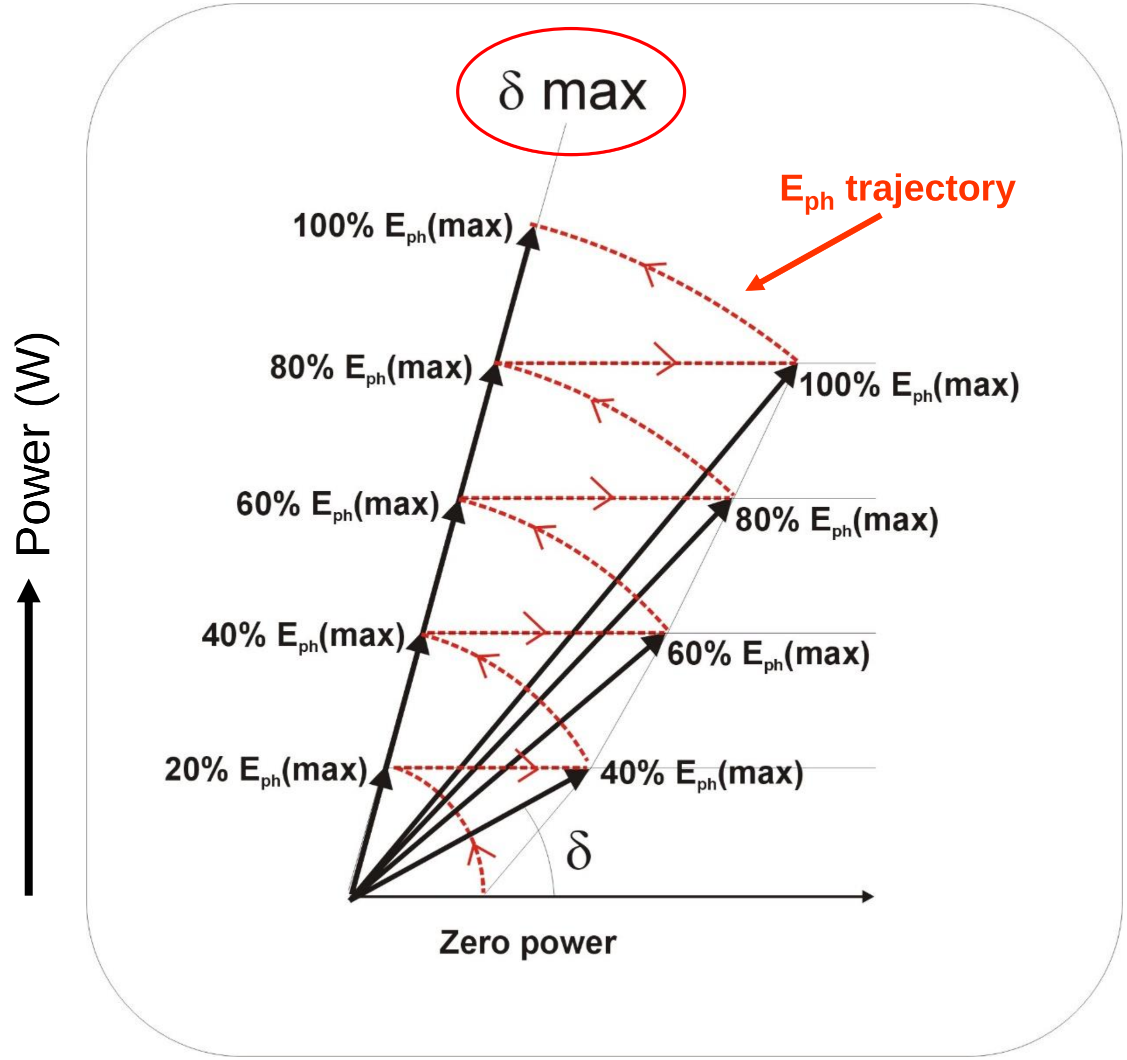


Operation OK if inside both circles and below Max Power line.

Final (possible!) Limitation: operate with as low a value of E_{ph} (I_f) as possible (minimise rotor losses) at any given operating point BUT include a 'Stability Margin'



Changing Eph (in 20% steps) as Power Increases from zero to Pmax



Eph is controlled (according to the power demand) such that it is kept to a 'minimum' value without δmax being exceeded

Starting at zero power a 20% E_{ph} value is selected. As power increases δ increases. When δ equals δmax E_{ph} is increases to its 40% value which causes an instantaneous reduction in δ (etc)

Summary

- Synchronous Generators come in 2 flavours:
  - PM Generators
  - Wound Field Generators
- 2 connection options:
  - Stand Alone Mode
  - Grid Connected
- Operating Limits of a Synchronous Generator:
  - Power limit from Prime Mover
  - Stator Current Limit
  - Rotor Current Limit