EE2022 Electrical Energy Systems

Generators

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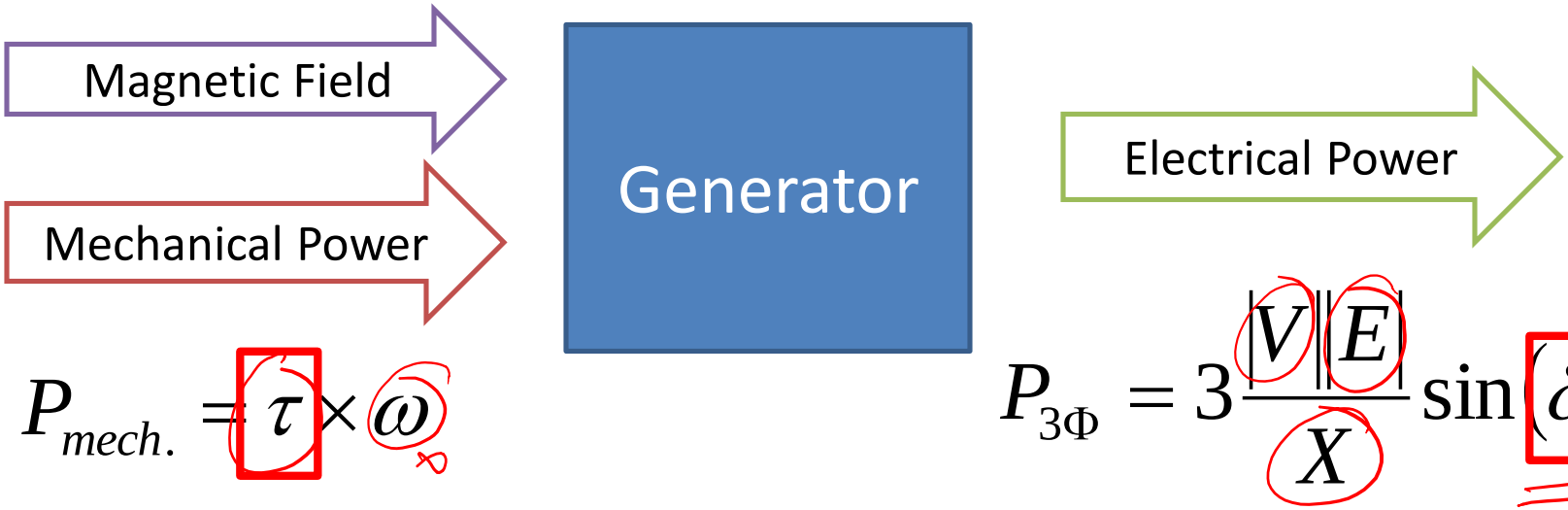
Department of Electrical and Computer Engineering

Control of complex power output

Loading capability of a generator

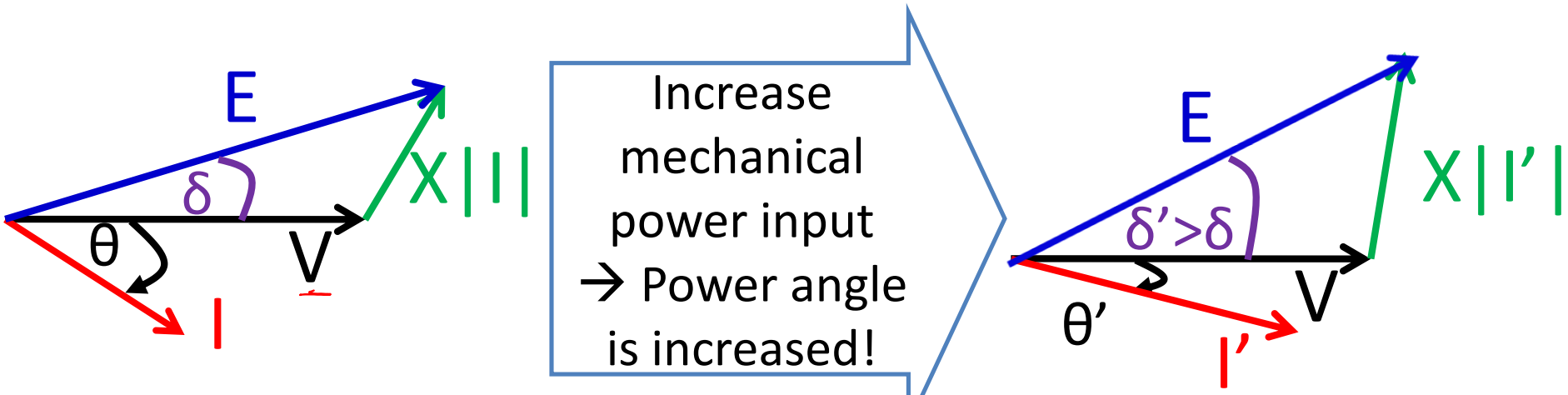
CONTROL OF REAL AND REACTIVE POWER OUTPUT

Real Power Output: Summary



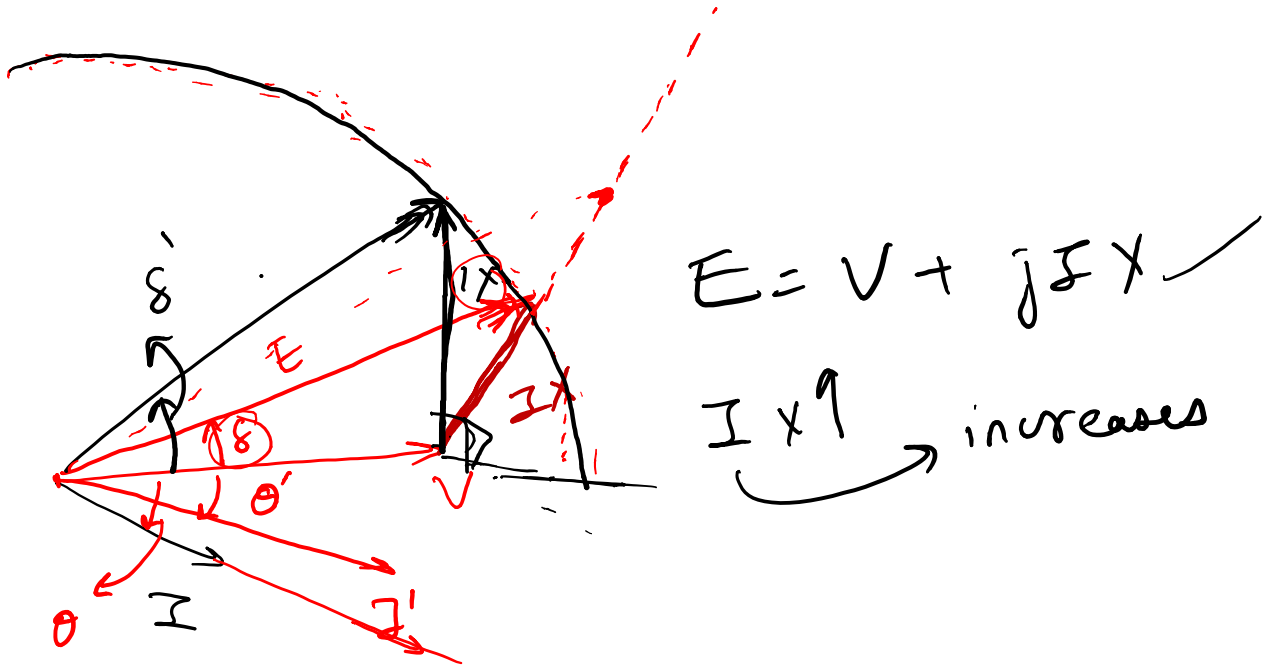
- Mechanical power input is increased by increasing the torque (τ). This results in a larger power angle and higher electrical power output.
- Steady-state stability limit is reached when power angle becomes 90 degrees.

Control of Real Power Output

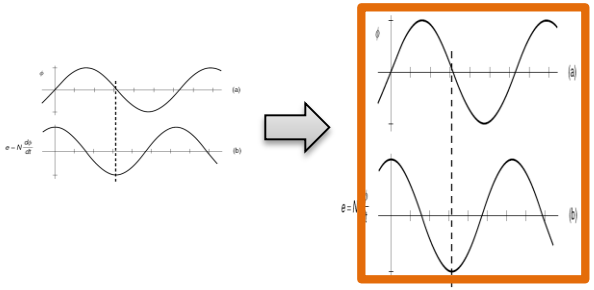


- |E|, |V| remains unchanged.
- Power angle increases as a result of higher mechanical power input.
- Load current |I| increases because the electrical power output is increased.
- The power factor will now change because the power angle is increased while the internal voltage magnitude is kept constant.
- We need to adjust the excitation voltage to keep the power factor constant.

Control of Real Power Output



Reactive Power Output: Summary



Magnetic Field

Mechanical Power

Generator

Electrical Power

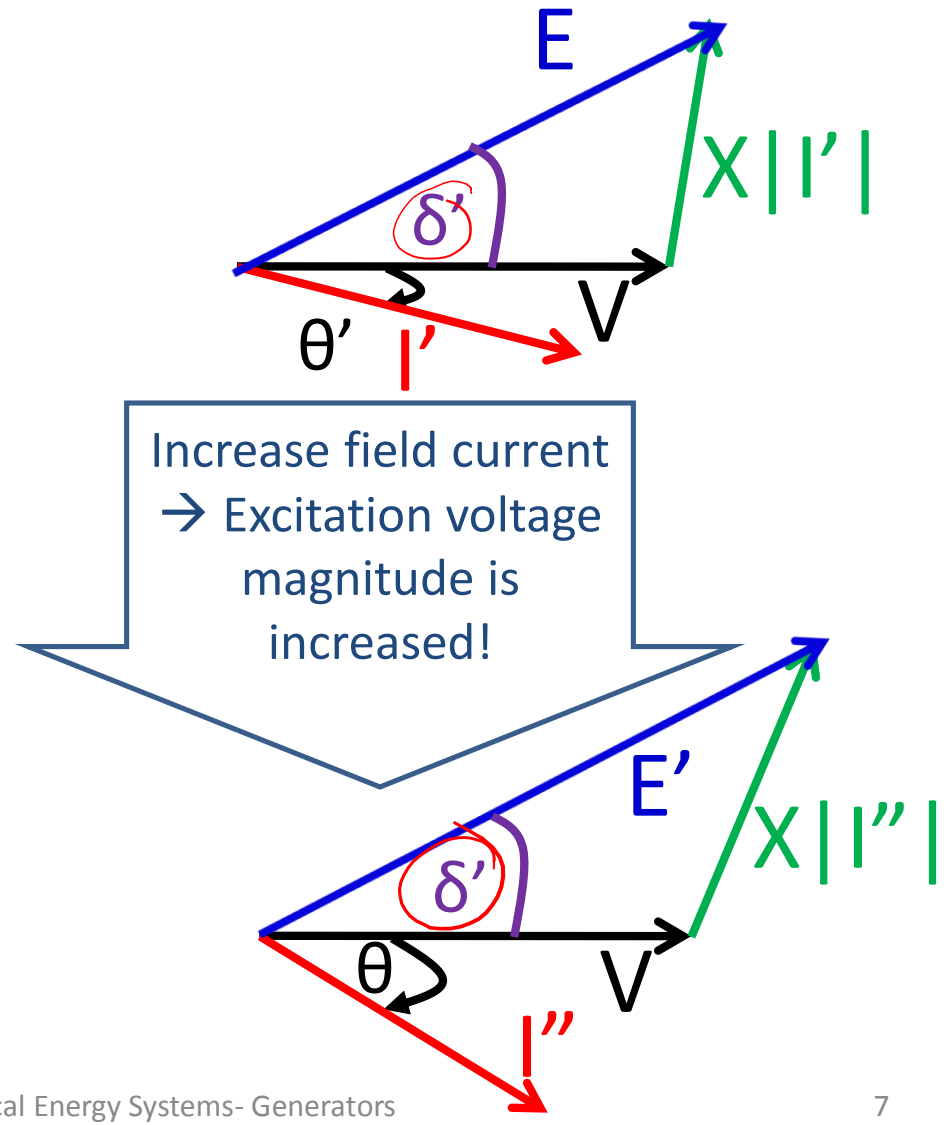
$$Q_{3\Phi} = 3\frac{|V||E|}{X}\cos(\delta) - 3\frac{|V|^2}{X}$$

- When we increase field current, the magnetic field is intensified. As a result, internal excitation voltage is increased. The reactive power output is increased.
- Two operating conditions of a generator: supplying reactive power is called overexcited and absorbing reactive power is called underexcited.

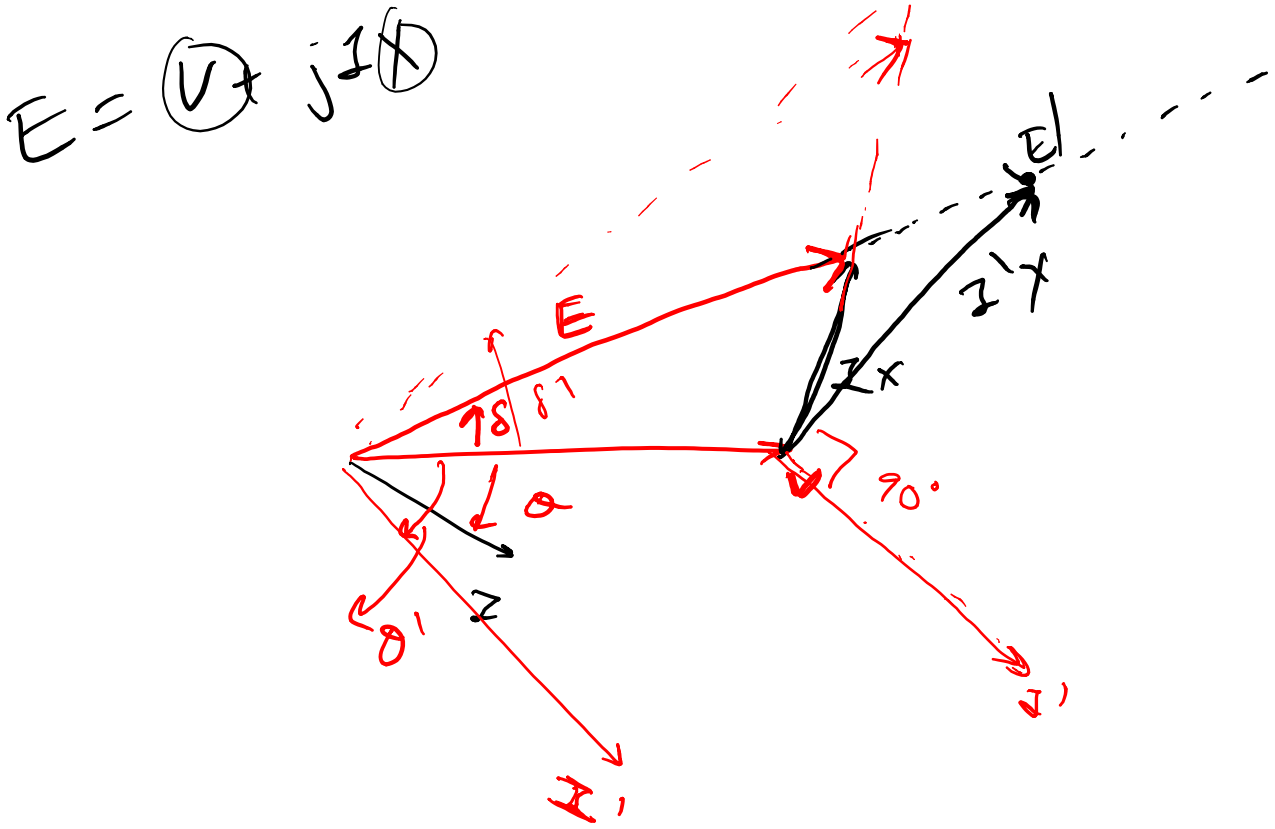
$(E\cos\delta - V)$

Control of Reactive Power Output

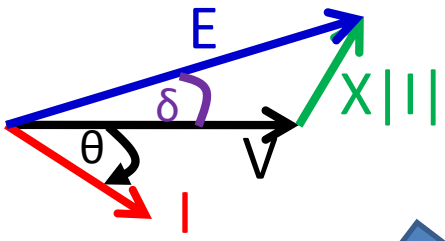
- |V|and power angle remains unchanged.
- The current magnitude and angle, θ (power factor) will change as a result of the change in excitation voltage magnitude.
- We can now adjust the excitation voltage to maintain the power factor of the original load.



Control of Reactive Power Output

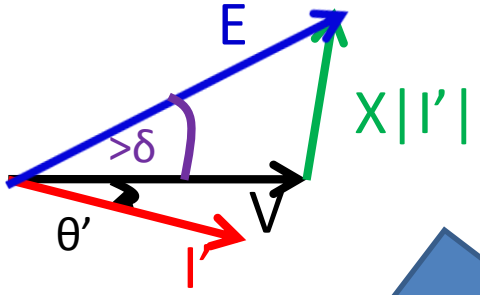


Control of Complex Power Supplied



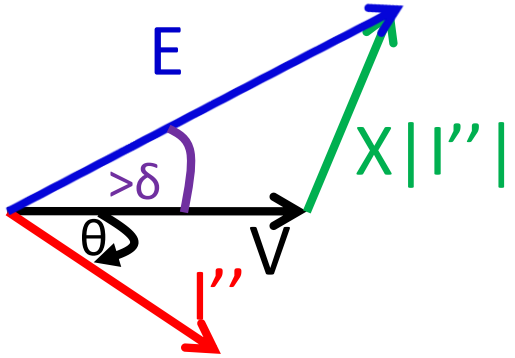
Vary the mechanical power input ➔ change in power angle.

δ



Vary the field current ➔ change in excitation voltage magnitude.

E



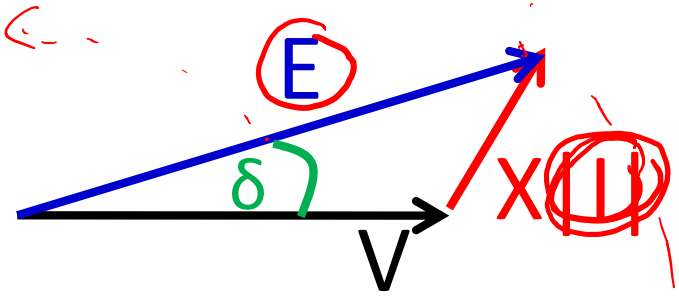
Loading Capability of a Generator

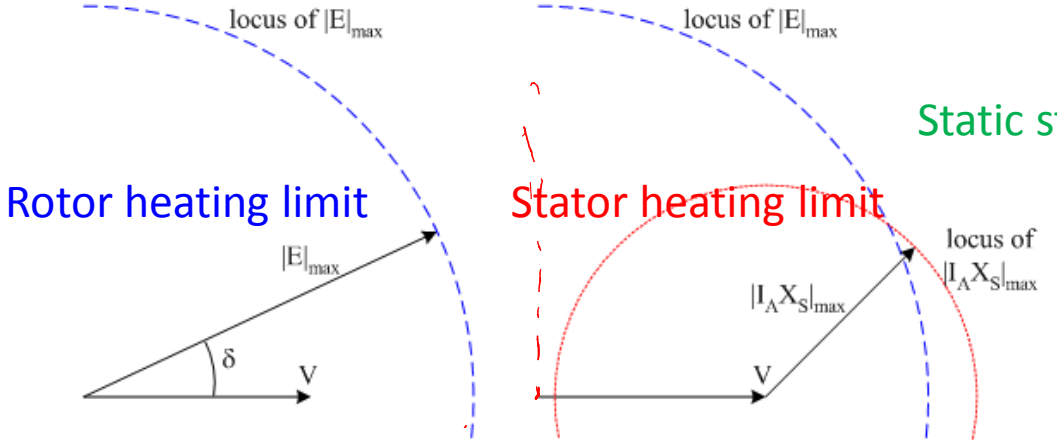
- Generator's loading capability is characterized by three main factors.
  1. Rotor heating limit: This limit is caused by the heating limit of a conductor in field winding at the rotor.
  2. Stator heating limit: This limit is caused by the heating limit of a conductor in armature winding at the stator.
  3. Stability limit: This limit is caused by the maximum power angle of 90 degrees before the machine runs out of synchronism.

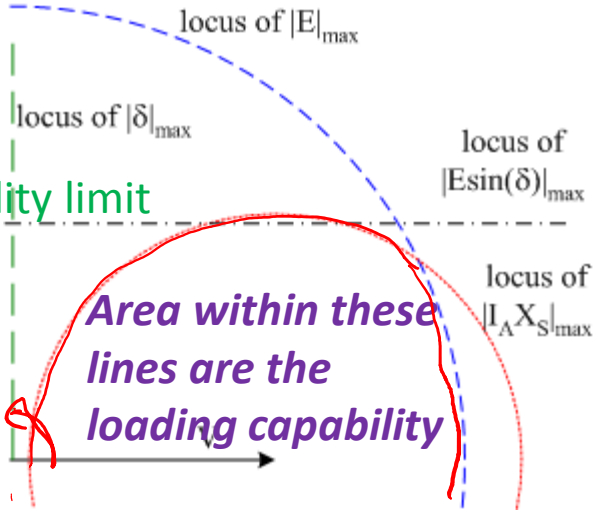
50MVA $P_m = 135MW$

Loading Capability of a Generator

- Rotor heating limit (field winding)
- Stator heating limit (armature winding)
- Stability limit (power angle)

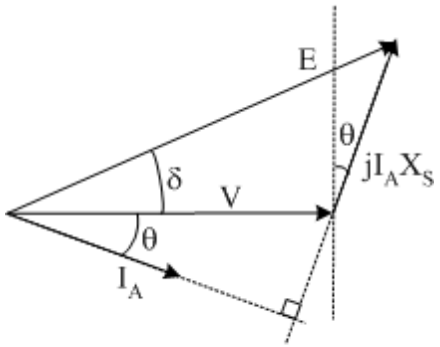






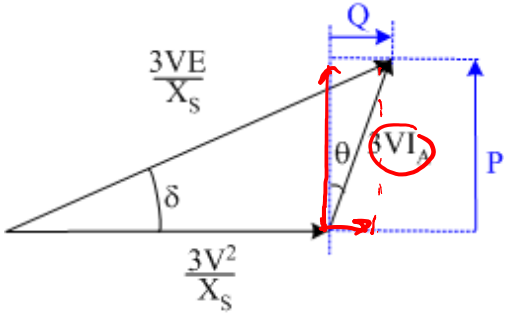
Source: http://www.ece.ualberta.ca/~knight/ee332/synchronous/ratings/power_limits.html

Power Limits of a Generator



Simplified Lagging Power Factor Phasor Diagram

Multiply by 3V/Xs

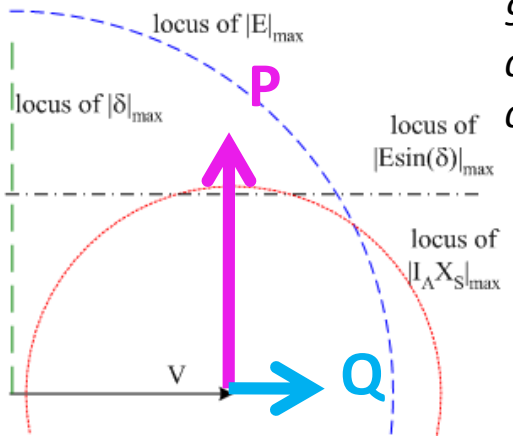


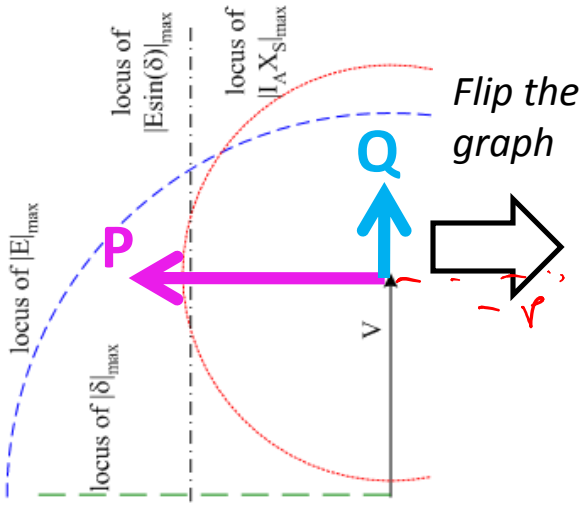
Scaled Lagging Power Factor Phasor Diagram

$$Q_{3\Phi} = 3\frac{|V||E|}{X}\cos(\delta) - 3\frac{|V|^2}{X}$$

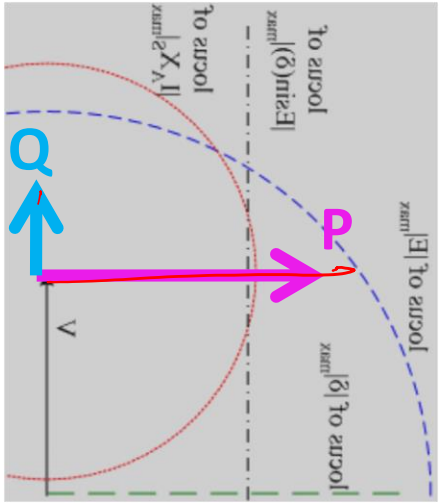
$$P_{3\Phi} = 3\frac{|V||E|}{X}\sin(\delta)$$

Rotate by 90 degree counter clockwise





Flip the graph



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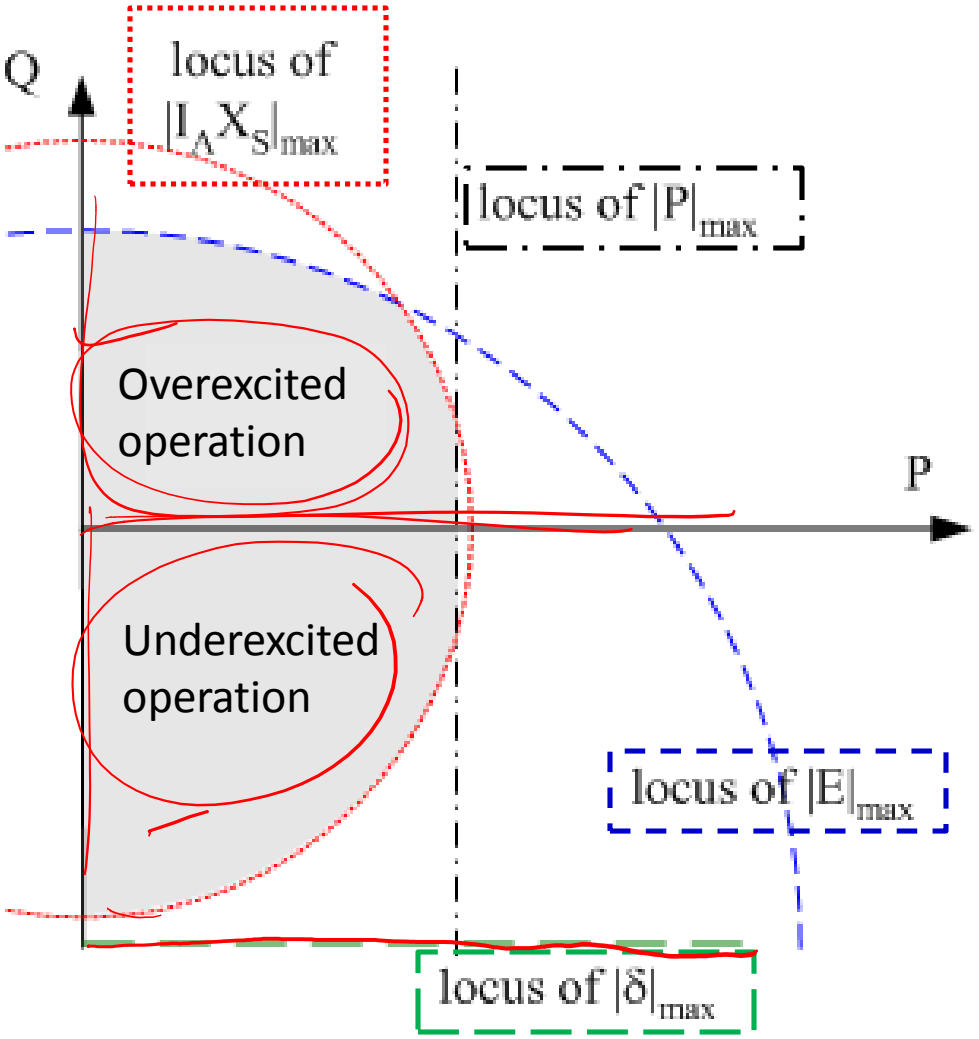
Generator Loading Capability



Generator Capability: Overexcited

Source: FACILITIES INSTRUCTIONS, STANDARDS,AND TECHNIQUES Volume 1-4 "**PERMISSIBLE LOADING OFGENERATORS AND LARGE MOTORS", FACILITIES ENGINEERING BRANCH DENVER OFFICE DENVER, COLORADO,** UNITED STATES DEPARTMENT OF THE INTERIORBUREAU OF RECLAMATIONREVISE D MARCH 1991

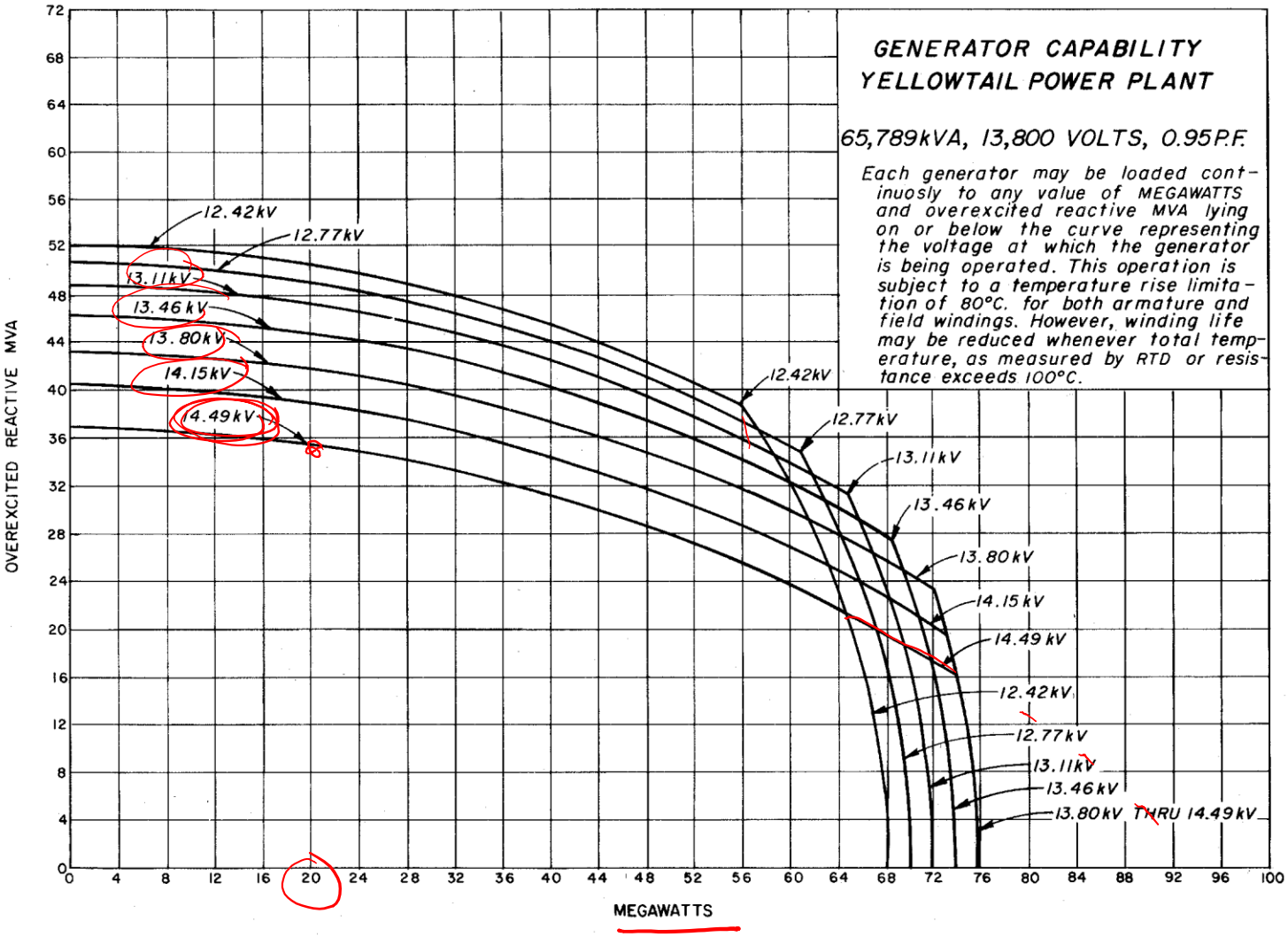


Figure 4. - Generator capability curve (overcited operation)

Generator Capability: Underexcited

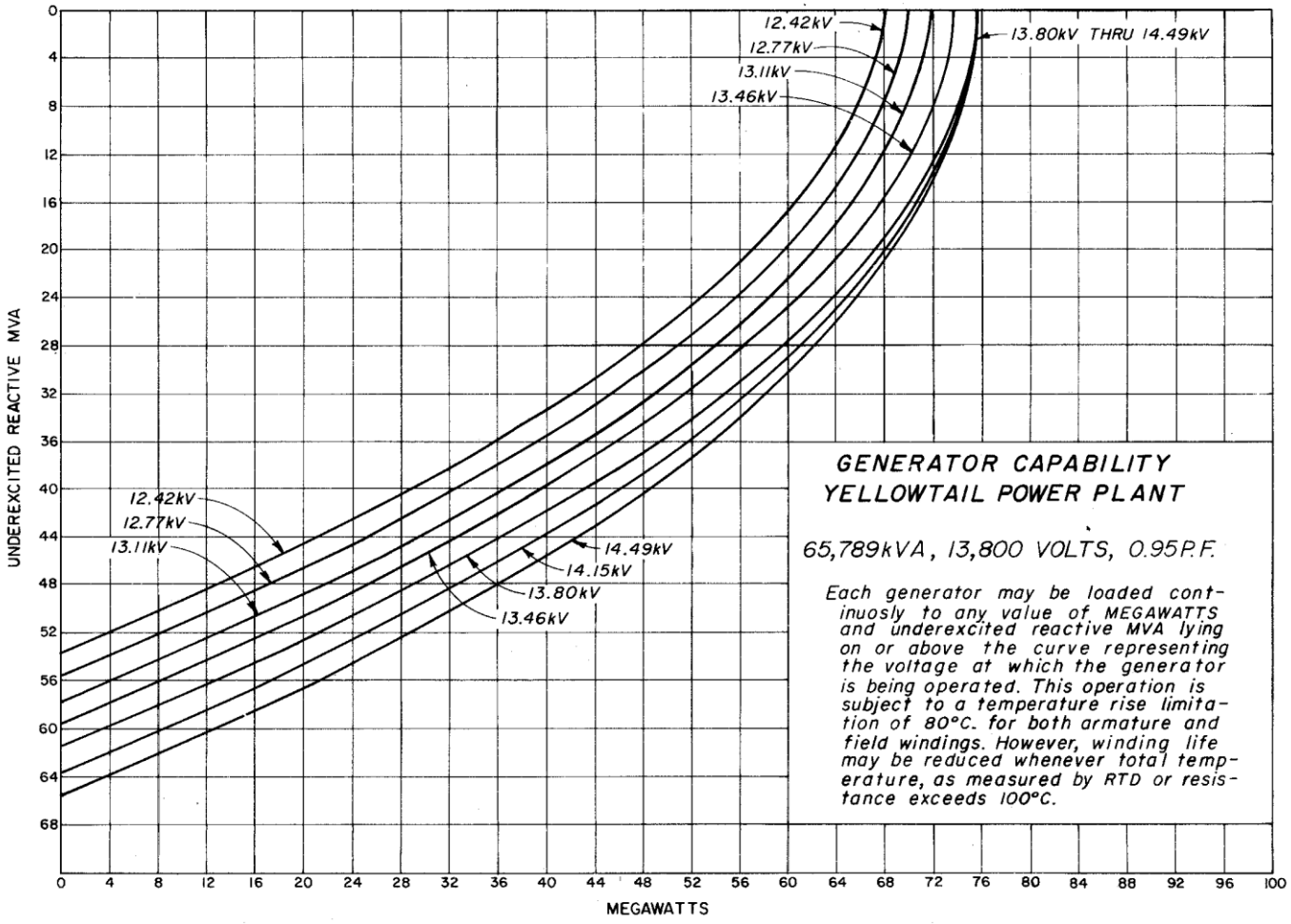
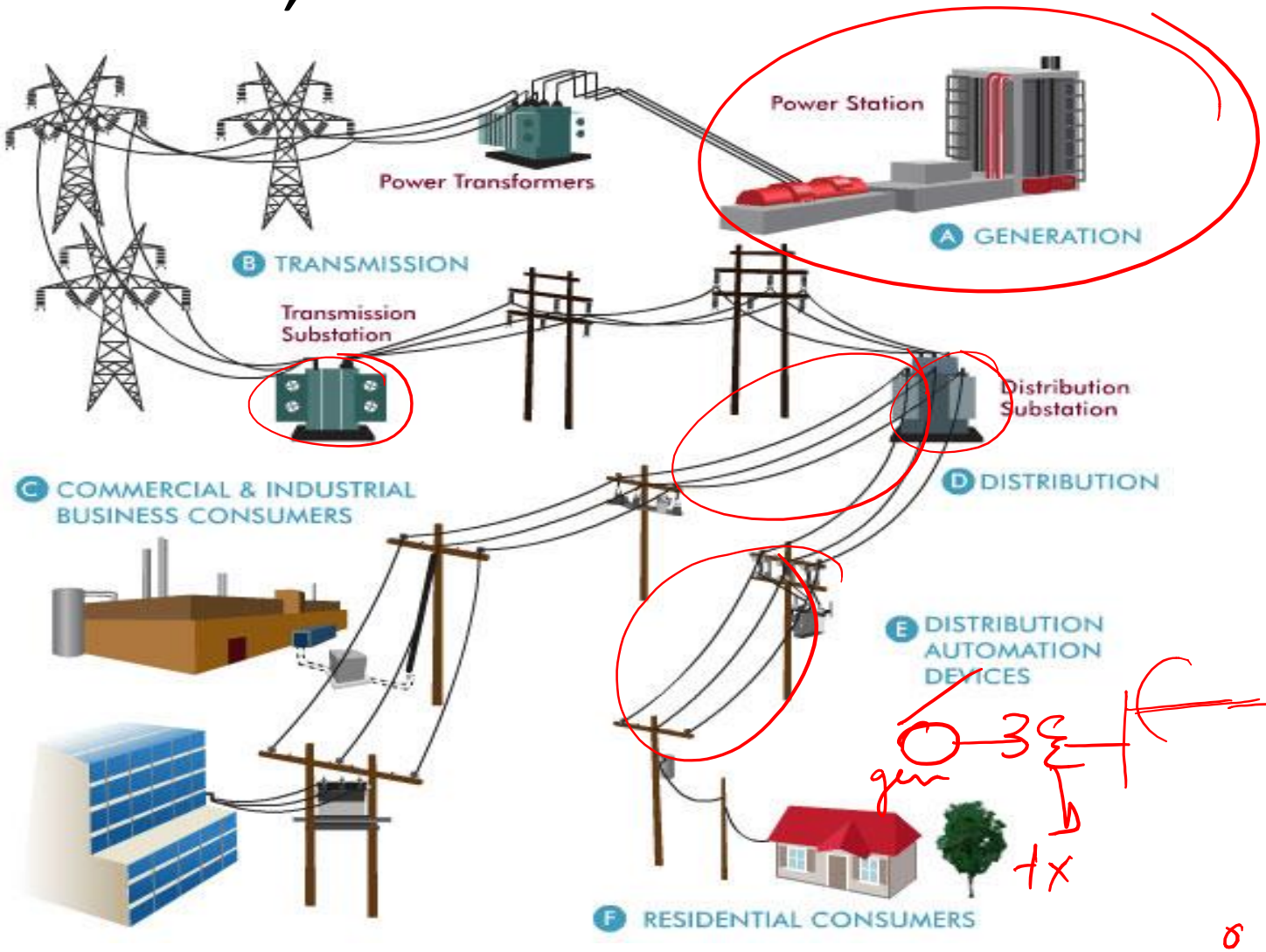


Figure 5. - Generator capability curve (underexcited operation).

Source: FACILITIES INSTRUCTIONS, STANDARDS,AND TECHNIQUES Volume 1-4 "**PERMISSIBLE LOADING OFGENERATORS AND LARGE MOTORS", FACILITIES ENGINEERING BRANCH DENVER OFFICE DENVER, COLORADO,** UNITED STATES DEPARTMENT OF THE INTERIORBUREAU OF RECLAMATIONREVISE D MARCH 1991

Generation, Transmission and Distribution



Source: http://venturebeat.com/2010/10/29/super-grid-introduction/

Summary

→ Real power output

$$P_{3\phi} = \frac{3|V||E|}{|X|}\sin\delta$$

$$E = V + jIX$$

→ Reactive power output

$$Q_{3\phi} = \frac{3|V||E|}{X}\cos\delta - \frac{3|V|^2}{X}$$

→ Rotor heating limit (E)

→ Stator heating limit (IX)

→ Stability limit ($\delta = 90°$ max power)

- Class Quiz
  - When : 5 pm, **Monday April 13, 2015**
  - Where: LT5
  - What: Generators
  - 3%
- Make up Mid Term
  - When : ~~5 pm~~, **Wednesday, April 15, 2015**
  - Where: To be Confirmed
  - What: Transformers, Per Unit System, Renewable Energy
  - 10%