National Association of Regulatory Utility Commissioners Energy Regulatory Partnership Program

Reactive Power

The Electricity Regulatory Authority of Albania
and
The Indiana Utility Regulatory Commission

Alva T. Such

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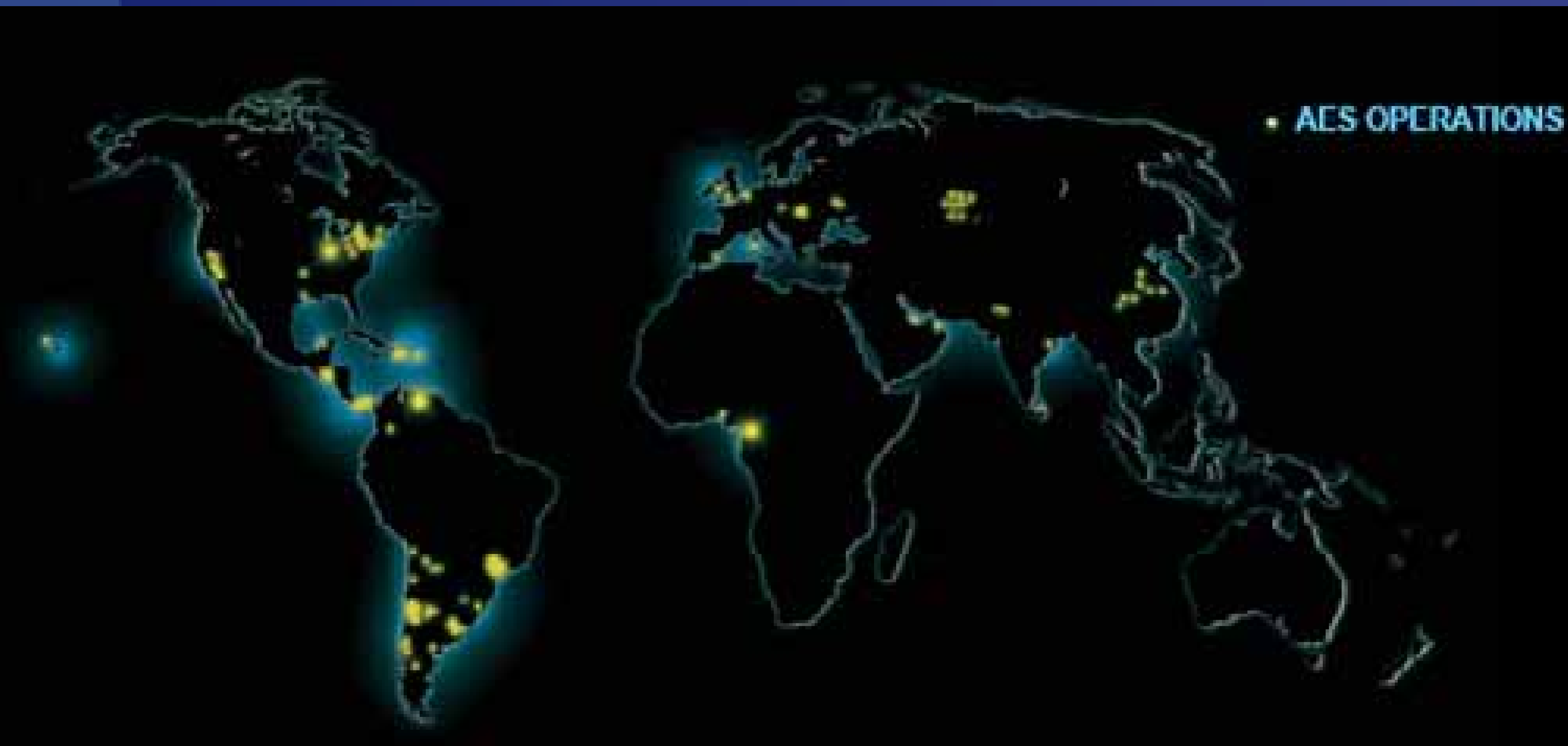
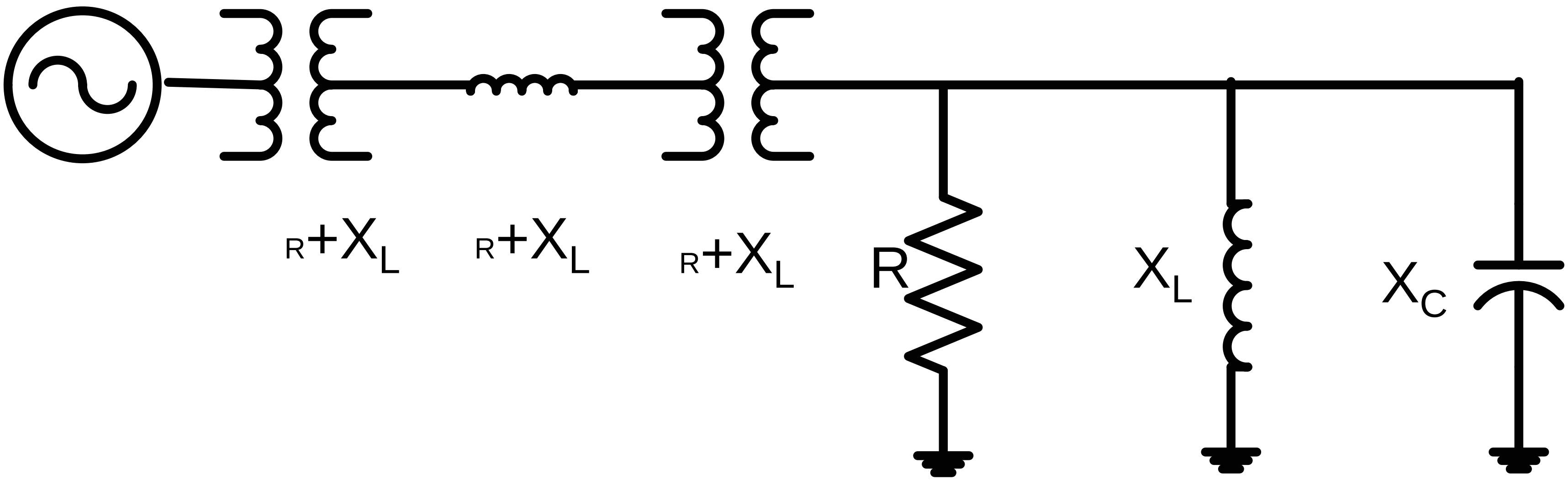
AES is Among the Largest Global Power Companies



Discussion Items

- Real, Reactive, and Apparent Power
  - What is it?
  - Implications
  - Power Factor Correction
- Perspectives
  - End-user
  - Utility
  - Regulatory

Electric System Impedance Diagram
Load Components



Resistive
- •Lights
- •Heat

Inductive
- •Motors
- •Transformers
- •Lines

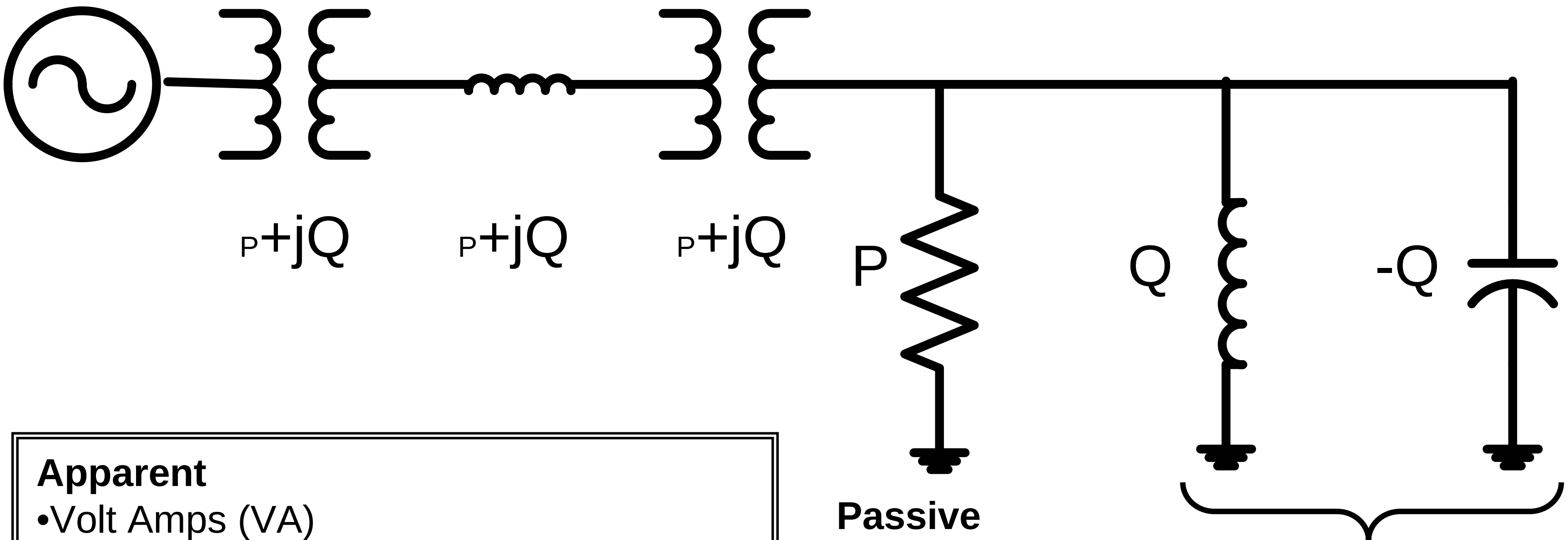
Capacitive
- •Capacitors
- •Light load transmission

Generation

Transformer

Tr

Electric System Impedance Diagram
Power Components



Apparent
•Volt Amps (VA)
- •Modulus of active and reactive power
- •Real and reactive power do not exist as separate entities. They are components of the power waveform.
- •S

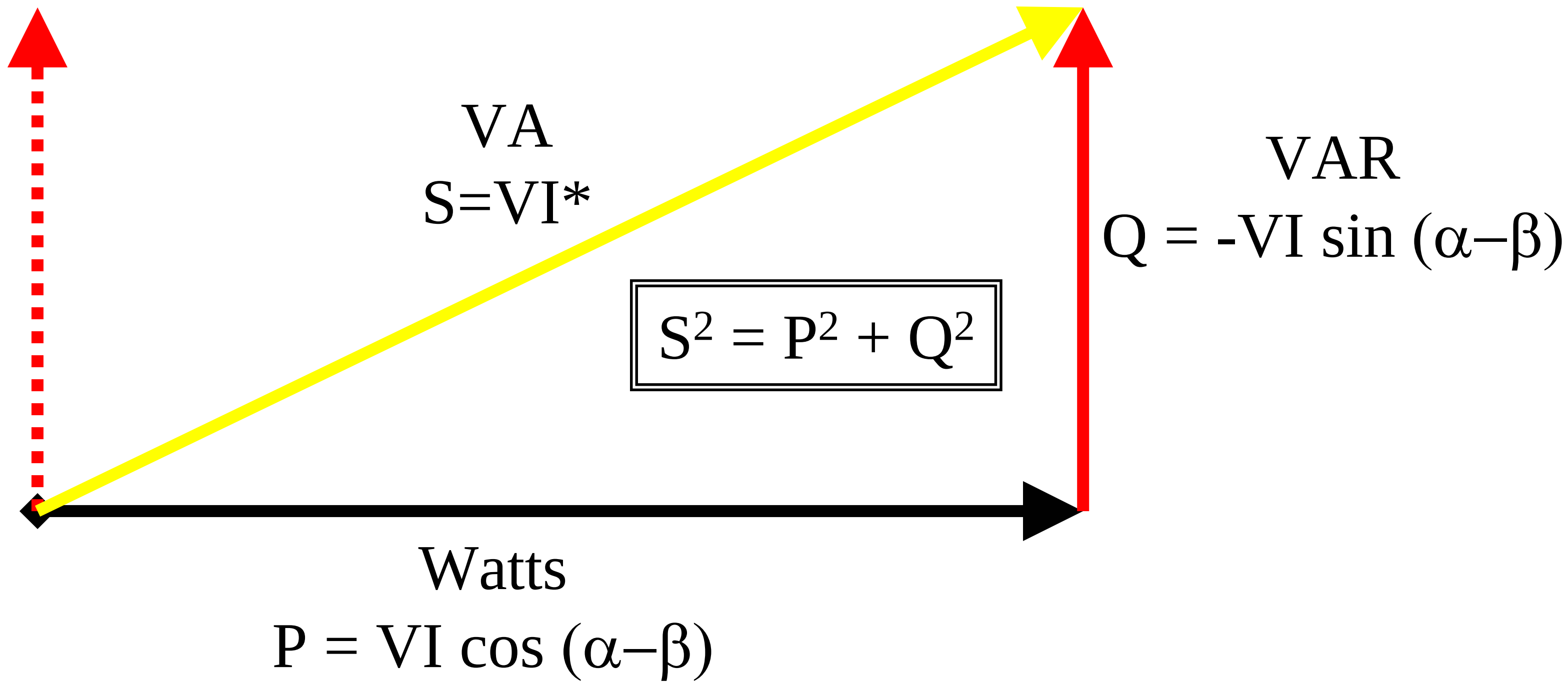
Passive
•Watts
•Active
•Real
•True
•P

Inductive **Capacitive**

<u>Reactive</u>
•Volt Amps Reactive (VAR)
•Imaginary
•Q

Generation Transformer T

Power Triangle

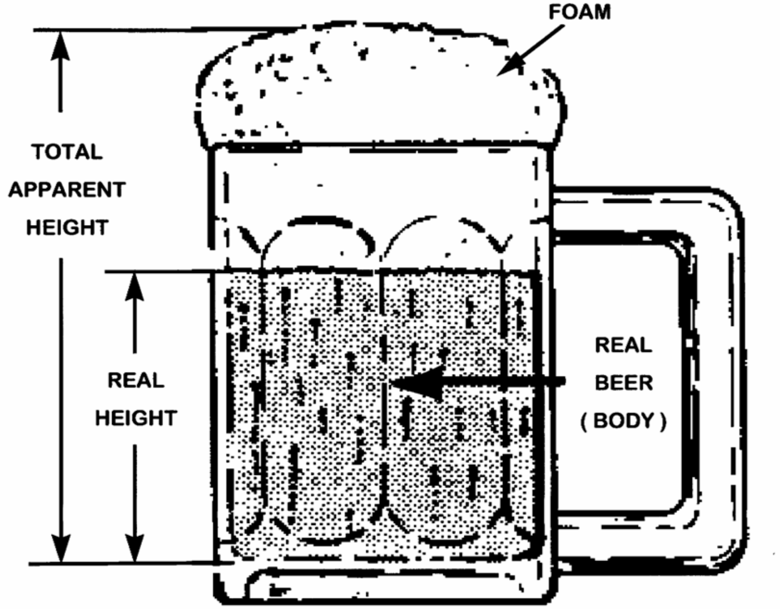


α = voltage angle
β = current angle

Power Factor

- Ratio of the active power to the apparent power (pf = P / S)
- pf = $\cos(\alpha-\beta)$
  - $\cos(\alpha-\beta) = 1 =$ unity power factor
  - Inductive
    - current lags the voltage.
  - Capacitive
    - current leads the voltage
- Theoretical ideal pf = 1
- Utility systems pf normally < 1

Power Analogy



A STEIN OF BEER CAN SERVE AS AN ANALOGY FOR POWER FACTOR . . .

APPARENT HEIGHT	=	VOLT - AMPERES	=	KVA
REAL HEIGHT	=	REAL POWER	=	KW
POWER FACTOR	=	$\frac{\text{REAL HEIGHT}}{\text{APPARENT HEIGHT}}$	=	$\frac{\text{KW}}{\text{KVA}}$

Reactive Power Definition

- Energy alternately stored in the load and returned to the source as the voltage alternates between positive and negative values.
  - This represents higher electric current flow.
- Reactive power does no useful work - *excess baggage*.
- Most AC systems are inductive reactive (most being inductive) due to motors and transformers.

Reactive Power Concerns

Although reactive power does no useful work, it cannot be ignored.

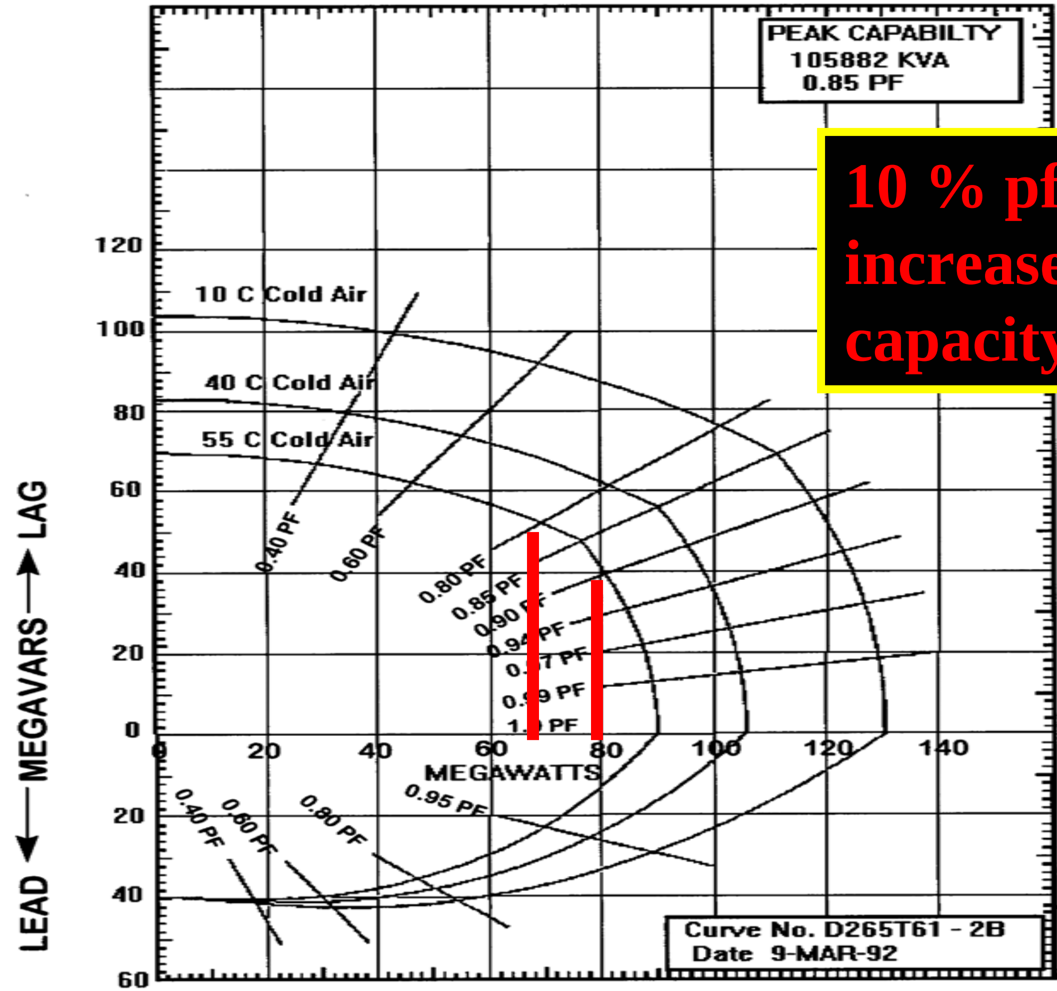
- System Capacity
  - Generation and delivery of reactive power requires additional electric system infrastructure.
- Voltage Regulation
  - Delivery of reactive power results in a greater voltage drop and less voltage regulation.
- Transmission of reactive power is very inefficient
- System losses.

Reactive Power vs. System Capacity

- Reactive power represents *additional current flow* on the generation and delivery systems.
- Delivery of reactive power reduces the systems ability to deliver real power.
  - Reduced generating capacity due to heating of windings.
  - The distribution system including conductors, breakers, switches, transformers, etc. must be sized to handle the additional current.
- Reactive power requires increased capital expenditure for higher capacity facilities and/or additional facilities.

Stout GT 4 & 5
Reactive Capability Curve

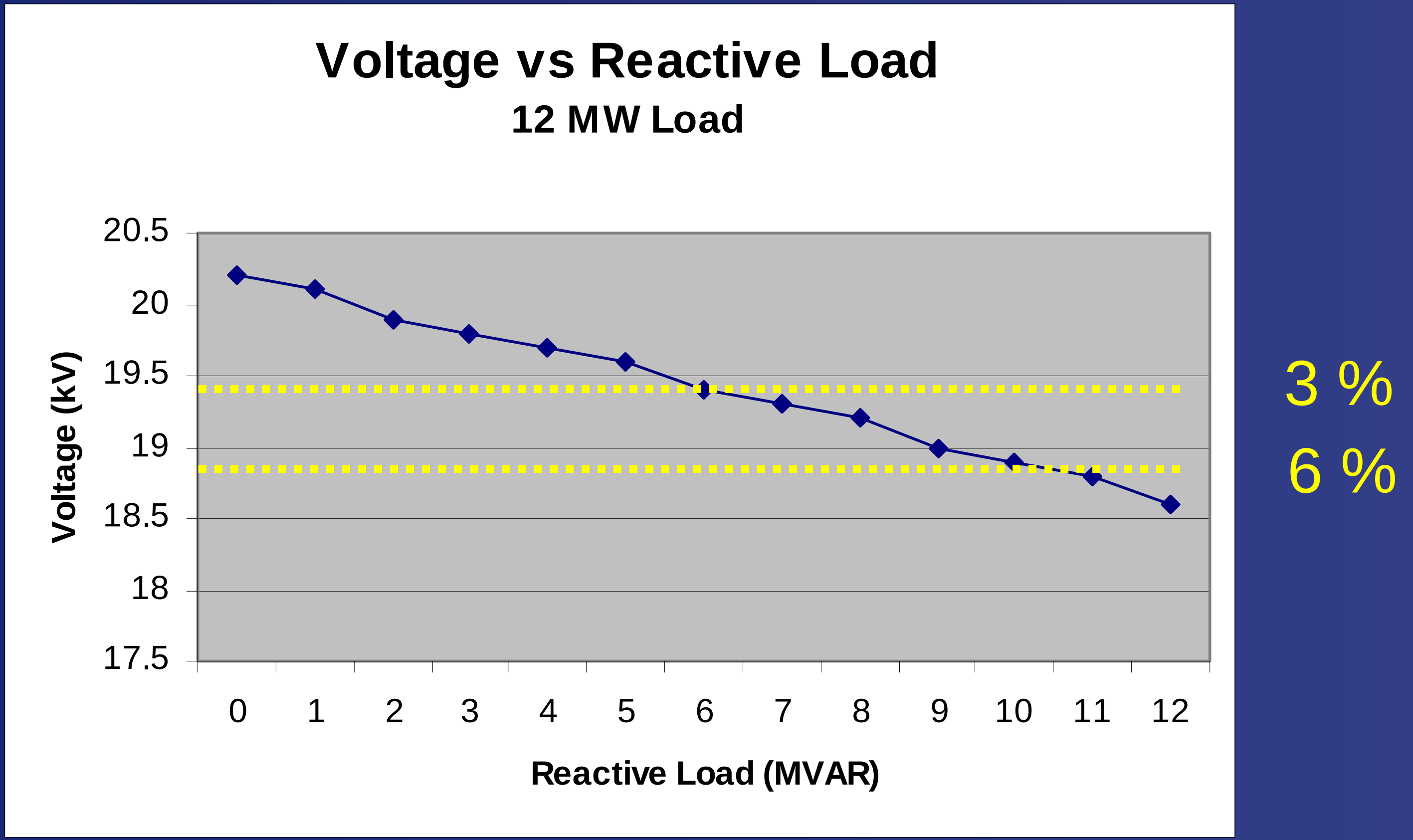
ESTIMATED REACTIVE CAPABILITY CURVES
104000 KVA - 3600 RPM - 13800 VOLTS - 0.80 PF
300 FLD VOLTS - 40 C COLD AIR - 0 FT ALT



10 % pf improvement increases generation capacity by 10 MW.

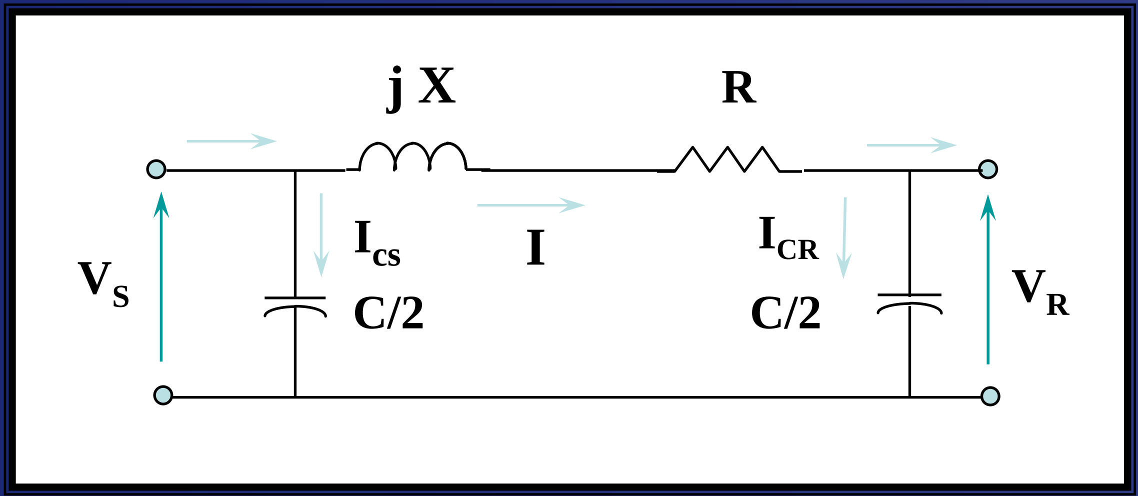
Voltage Regulation

- Reduce voltage regulation due to voltage drop across system X_L (IX_L)



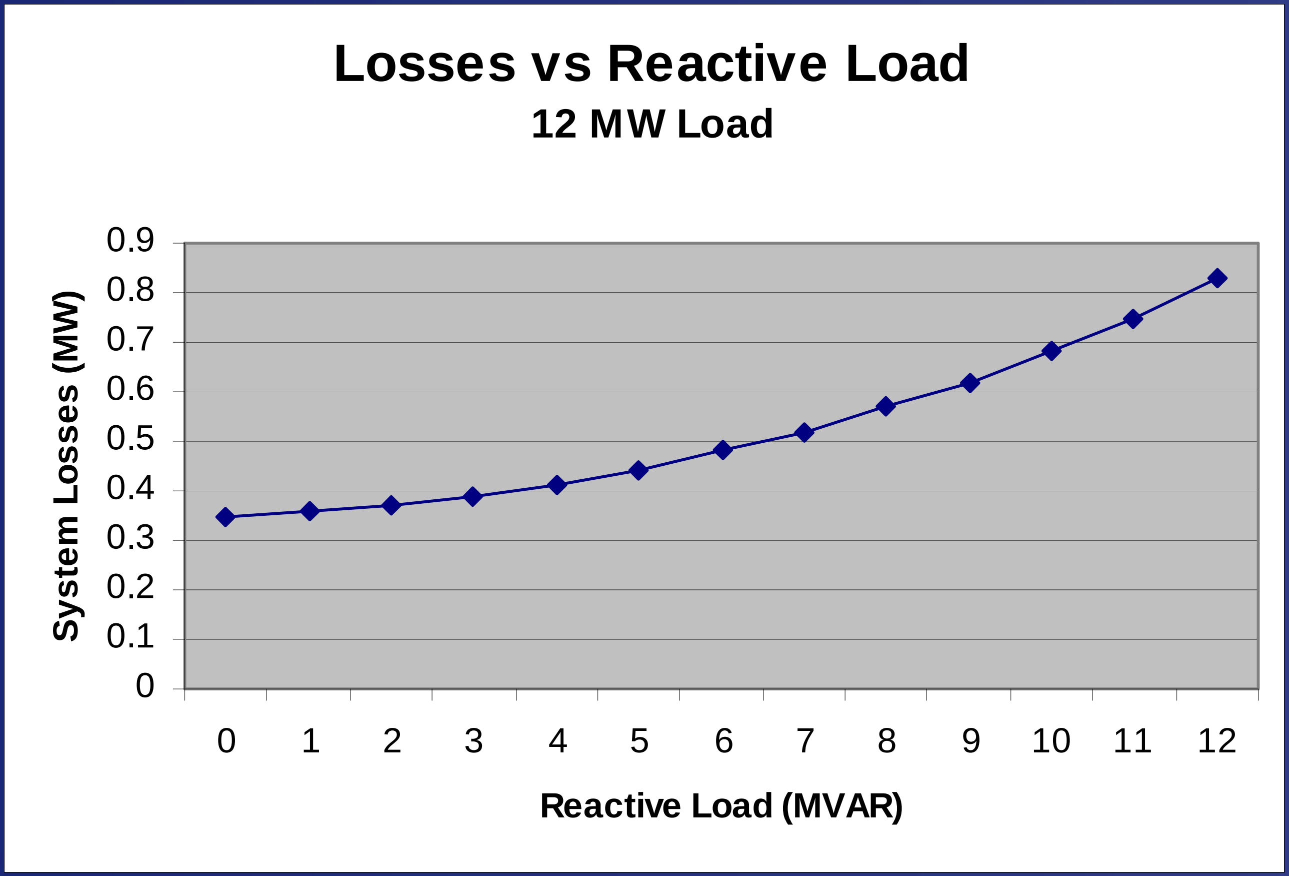
Delivery of Reactive Power

- Due to transmission line characteristics, reactive power cannot be delivered over long distances. The delivery of reactive power increases the current
  - which increases the lines reactive power requirements by the square of the current, and
  - Increases the voltage drop



Increased System Losses

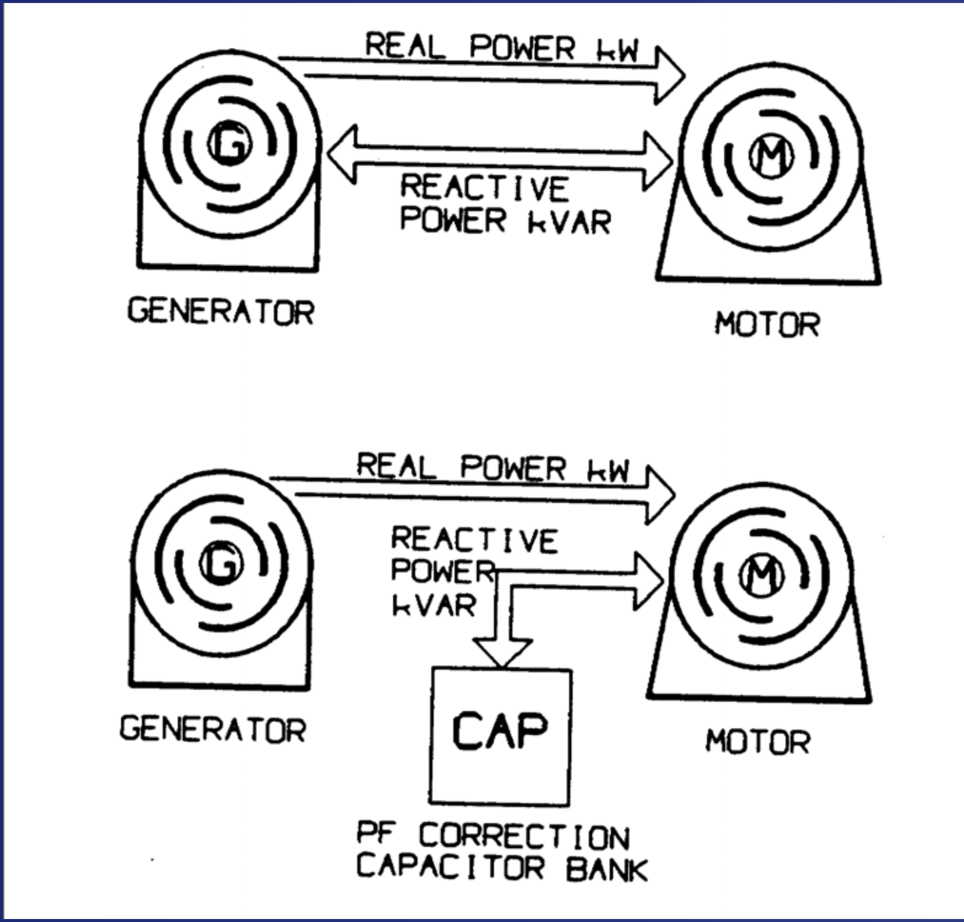
- Increased system losses due to I^2R.



Reactive Power Sources

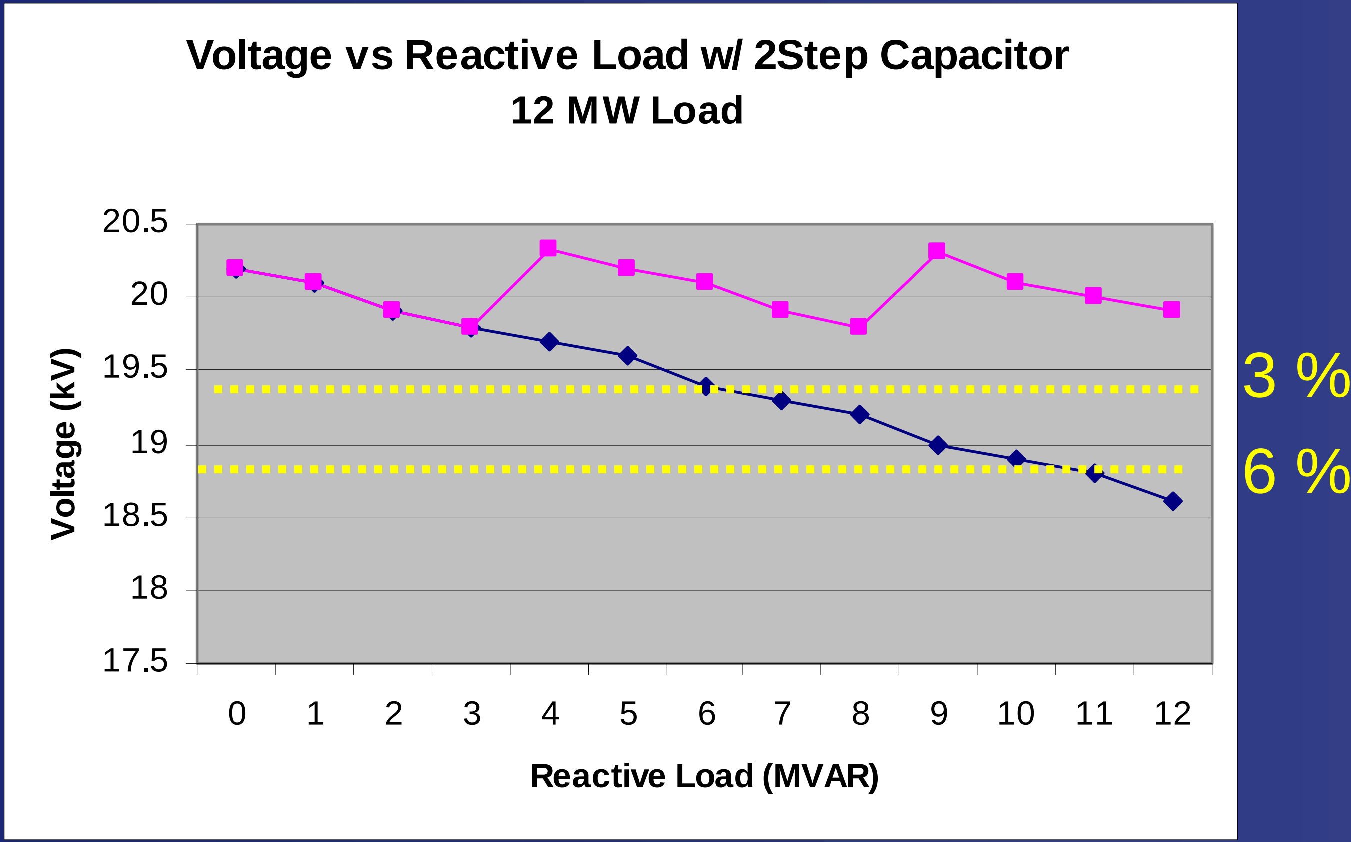
- Generation
  - Often located near fuel source and away from the load – reactive power cannot be delivered over long distances.
  - Very expensive
- Capacitance
  - Easily located near load
  - Relatively low maintenance
  - Inexpensive
  - Normally controlled in increments
- Static VAR Compensators
- Synchronous motors

Power Factor Correction



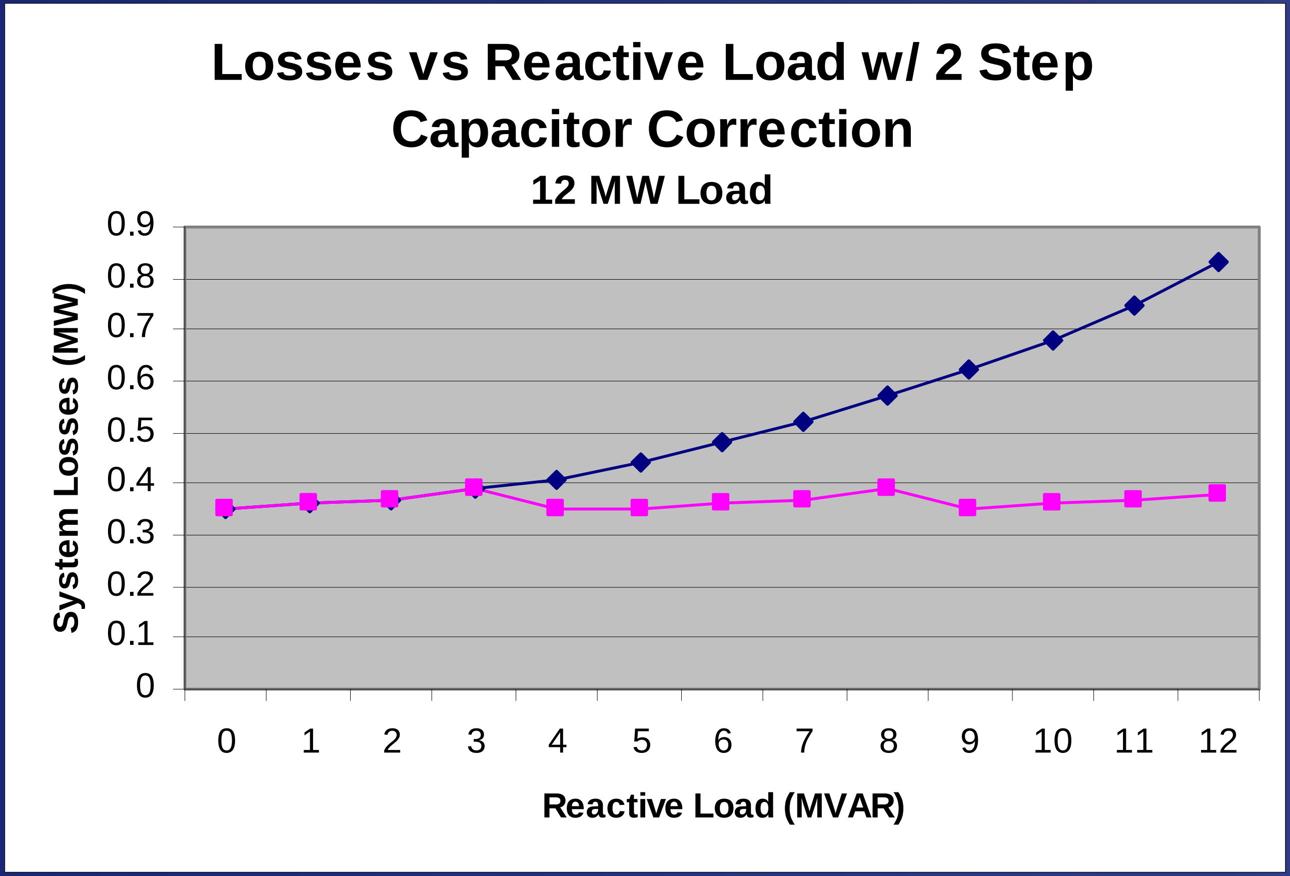
Voltage Regulation

- Power factor correction capacitors reduce reactive current flow and the voltage drop across system X_L (IX_L)



Increased System Losses

- Power factor correction capacitors reduce reactive current flow and the losses across system $X_{L.}$ (I^2X_L)



End-User Concerns

- Power Factor Penalties
- Voltage regulation
  - Internal, large campus
  - Utility
- System resonance for pf correction capacitors
- Efficient use of electric system
  - Transformers

Utility Concerns

- Voltage Regulation
  - Low voltage
  - Voltage collapse
  - Reactive power cannot be delivered over large distances
- Efficient use of system assets
  - Cost of facilities
- Losses
- Ancillary Services
  - Reactive power support from adjacent utilities, potential cost

Regulatory Perspective

- Financial
  - Each Customer pay a fair value for the energy delivered and resources consumed.
- Reliability
  - The electric system provides a very high level of system reliability. Encourage large customers to cover their own reactive power requirements to facilitate voltage regulation

Regulatory Perspective

1. Reactive power reliability needs should be assessed locally, based on clear national standards.
2. These needs should be procured in an efficient and reliable manner.
3. Those who benefit from the reactive power should be charged for it.
4. All providers of reactive power should be paid, and on a nondiscriminatory basis.

Regulatory Perspective
Financial

- High pf users – efficiently utilize electric systems
- Low pf users – inefficient use of electric system resources normally required to pay for these resources through a power factor penalty.

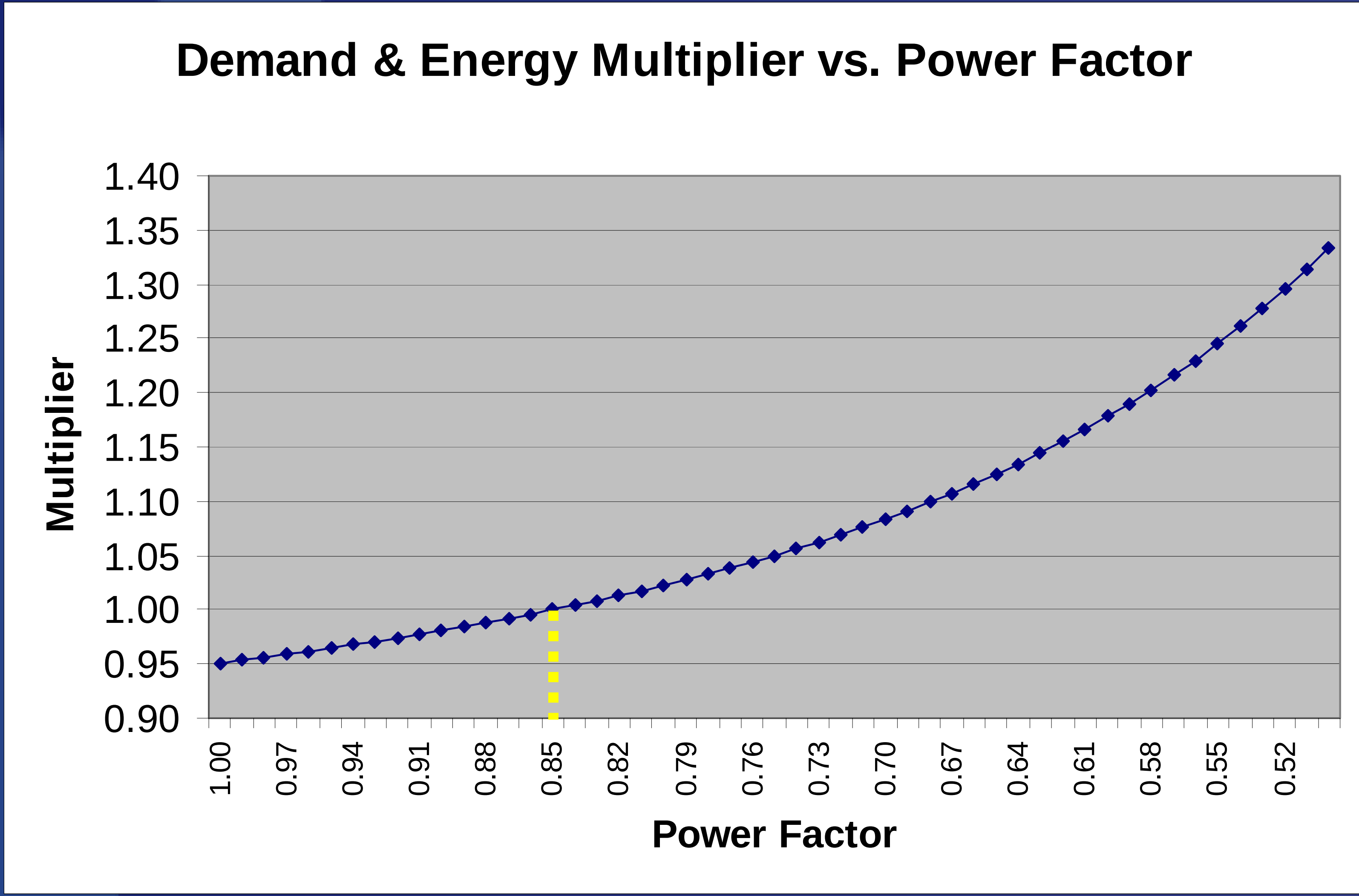
Reactive Power Design

- System configuration
  - Location of load
  - Location of generation
  - Transmission capacity
- Load characteristics
- Voltage regulation options

Reactive Power Tariff Methods

- Power factor based
- Reactive power peak demand (VAR)
- Reactive power requirement (VARHr)
- kVAHr

IPL Power Factor Multipliers



Reactive Power Charges

- Minimum
  - Cost of capacitance (1 per unit)
- Maximum
  - Cost of generation to provide reactive power (up to 20 per unit)
- Pricing consistency is probably more important since the end-user should be able to adjust to tariff and eliminate reactive power charges

Thank You