A
Presentation on
Reactive Power Pricing

What is Reactive Power?

- In an alternating current circuit both the current and voltage are sinusoidal and power is expressed as the product of current and voltage. In a simple resistive circuit the voltage and current are in phase, the real power is equal to the apparent power and no reactive power flows.
- However when the voltage and current pass through certain types of circuits (inductive or capacitive) the voltage and current become out of phase. This phase separation is usually called the Power factor and the current is said to lag or lead the voltage.
- It is defined as the product of the rms voltage, current, and the sine of the difference in phase angle between the two. Reactive power is usually denoted *Q* and expressed in volt-amperes reactive, or *var* (not watts). This is to avoid confusion when specifying the power of a load (var automatically refers to reactive power).

Contd..

What is Reactive Power? (Contd..)

- Reactive power is associated with the reactance of a load, and unlike active power, can be positive or negative. A purely inductive load is associated with a negative reactive power and lags the active power by 90 degrees.
- A purely capacitive load is associated with a positive reactive power and leads the active power by 90 degrees.
- To maintain efficient transmission, it is often necessary to reduce the magnitude of the reactive power in a system. This is known as power factor correction.
- If there is a phase separation between the Voltage and Current, the instantaneous power will have to 'work' harder to produce the equivalent power as if they were in phase.

Contd..

What is Reactive Power?

- Reactive power is described as the amount of power required to overcome the phase shift between the current and voltage. It is generally regarded as waste power as it is used to 'energize' the circuit to allow it do useful work.

- Reactive Power as such cannot do any work and is merely a facilitator to do some useful work by Active power. (Analogy)

- Capacitive circuits generate reactive power and inductive circuits absorb reactive power. If large quantities of reactive power (positive or negative) are present then the overall power factor will be low.

Reactive Loads

- Electric motors, Transformers, electromagnetic generators and alternators used for creating alternating current are all components of the energy delivery chain which require reactive power.

- Losses incurred in transmission from heat and electromagnetic emissions are included in total reactive power.

- The reactance (X) of a transmission system is many times the resistance (R) as a result the voltage drops (inductive and total) becomes sizeable. End voltages drops down. This is the reason to say that the reactive power and voltage are closely coupled.
- The power delivered also goes down creating lost opportunity to sale.

- Dynamic reactive power supplied locally, near the load, has more of an impact than when supplied from distant generators.

Reactive Power Supply is an Ancillary Service

- Reactive power supply is one of a class of power system reliability services collectively known as ancillary services, and is essential for the reliable operation of the bulk power system.
- Reactive power is energy which must be produced for maintenance of the system and is not produced for end-use consumption.
- The reactive power absorbed by a transmission line or transformer is proportional to the square of the current. It compounds the losses by lowering supply voltages. Reactive power flow wastes energy and capacity.
- Because of this, it is difficult to supply reactive power over long distances, it "Does Not Travel Well".
- Reactive power can be supplied from either static or dynamic VAR sources (capacitors or generators). To correct lagging power flow, leading reactive power (current leading the voltage) is supplied to bring the current in phase with voltage.

Why is the need for local reactive power growing?

- There are growing instances of "micro voltage collapse" in distribution systems. A voltage collapse occurs when the system is trying to serve more load than the voltage can support.

- Newer loads are causing higher peaks and worse power factors. Loads like CFLs (PF of 0.5), Discharge lamps, fluorescent lamps, 1-phase Arc-welding sets, Thyristor loads etc.

- Load growth on existing circuits has created unforeseen voltage problems.

Why do we need a tariff?

- As per the IEGC Code and Grid Connectivity Standards issued by Central Electricity Authority (CEA), the DISCOMs shall not depend on the Grid for Reactive Power.

- Having the distribution substations at a slightly leading PF would improve capacity on the transmission system.

- Providing local supplies of dynamic reactive power would reduce losses, increase capacity, and increase the margin to voltage collapse.

GTCS Condition of PF

- The consumers are supposed to maintain a minimum PF of 0.95 lag.
- If PF falls below 95%, consumers have to pay penal charges as per tariff order.
- Consumers can draw reactive power at free of cost after maintaining 0.95 pf.

Drawback in Present practice - an example

- Customer A draws 500 kW active power and 242 kVAr reactive power at 0.90 pf
- Customer B draws 100 kW active power and 62 kVAr reactive power at 0.85 pf.
- Here Customer 'A' is drawing 242 kVAr of Reactive Power which is more than customer 'B's reactive power of 62 kVAr.
- Who is causing more loss to the system?
- Obviously consumer 'A' is causing more loss than Consumer 'B' to the System.
- As per the TO, Consumer B pays penal charges.
- The technical loss and resulting lower voltage and corresponding compounding losses caused by 'A' are shared by all consumers.

Drawback in Present practice and Conclusion

- There is no logic in fixing floor penalty levels - first at 0.90 and now at 0.95pf.
- Consumer drawing more reactive power causes more loss and inconvenience to the system and has to pay more.
- The present billing is done for Active Power (VI Cos Ø - Horizontal vector). But the power drawn by the consumer is Apparent power (VI - Hypotenuse).
- If billing is done for both active and reactive power, we can overcome the drawback.

Reactive power Pricing

- The solution is proper Reactive Power Pricing.
- Reactive Power tariff can be levied in two ways.
- (a) By fixing separate reactive power tariff along with kWh tariff.
- (b) By fixing kVAh tariff which includes both active and reactive power.
- As already stated, the power drawn from the system is Apparent Power (Diagonal Vector) and not the kW power.

Benefits of Reactive power pricing

- If the tariff is fixed on the basis of kVAh (Apparent Power), no consumer will draw reactive power. The consumer would always generate reactive power locally by installing Capacitors.
- Either they draw minimum reactive power or no reactive power. If reactive power is consumed, the Licensee gets their share of revenue.
- As a result the PF will reach to near unity.
- Hence, the resultant power (apparent power) will come down.
- I^2R losses will come down.
- System Voltages will improve.
- The Transmission capacity will increase.
- Increases the margin to voltage collapse.

Effective kVArh Tariff Sample Calculation

- Sample calculation considering 100 kW load for one hour consumption and kVAh/kWh unit cost @ Rs 1.00 per unit is furnished for understanding reactive power drawal effect.

- The effective kVArh tariff varies from 0 to 82% of kVAh/kWh tariff for power factor variation of Unity to 0.20

- Contribution of kWh component and kVArh component to kVAh tariff is shown with the help of Graph

Sample Calculations @ Re. 1.00/kVAh

Sl. No	kW	Power Factor	KWH	kVArh	kVAh	Rs./unit	With kVAH Tariff	kWh Contribution	kVArh Contribution	Effective kVArh Tariff
1	100	100.00%	**100**	**0**	**100.00**	**1**	**100.00**	100	0.00	0.00
2	100	98.00%	**100**	**20**	**102.04**	**1**	**102.04**	100	2.04	0.10
3	100	95.00%	**100**	**33**	**105.26**	**1**	**105.26**	100	5.26	0.16
4	100	90.00%	**100**	**48**	**111.11**	**1**	**111.11**	100	11.11	0.23
5	100	85.00%	**100**	**62**	**117.65**	**1**	**117.65**	100	17.65	0.28
6	100	80.00%	**100**	**75**	**125.00**	**1**	**125.00**	100	25.00	0.33
7	100	75.00%	**100**	**88**	**133.33**	**1**	**133.33**	100	33.33	0.38
8	100	70.71%	**100**	**100**	**141.42**	**1**	**141.42**	100	41.42	0.41
9	100	70.00%	**100**	**102**	**142.86**	**1**	**142.86**	100	42.86	0.42
10	100	65.00%	**100**	**117**	**153.85**	**1**	**153.85**	100	53.85	0.46
11	100	60.00%	**100**	**133**	**166.67**	**1**	**166.67**	100	66.67	0.50
12	100	55.00%	**100**	**152**	**181.82**	**1**	**181.82**	100	81.82	0.54
13	100	50.00%	**100**	**173**	**200.00**	**1**	**200.00**	100	100.00	0.58
14	100	45.00%	**100**	**198**	**222.22**	**1**	**222.22**	100	122.22	0.62
15	100	40.00%	**100**	**229**	**250.00**	**1**	**250.00**	100	150.00	0.65
16	100	35.00%	**100**	**268**	**285.71**	**1**	**285.71**	100	185.71	0.69
17	100	30.00%	**100**	**318**	**333.33**	**1**	**333.33**	100	233.33	0.73
18	100	25.00%	**100**	**387**	**400.00**	**1**	**400.00**	100	300.00	0.77
19	100	20.00%	**100**	**490**	**500.00**	**1**	**500.00**	100	400.00	0.82

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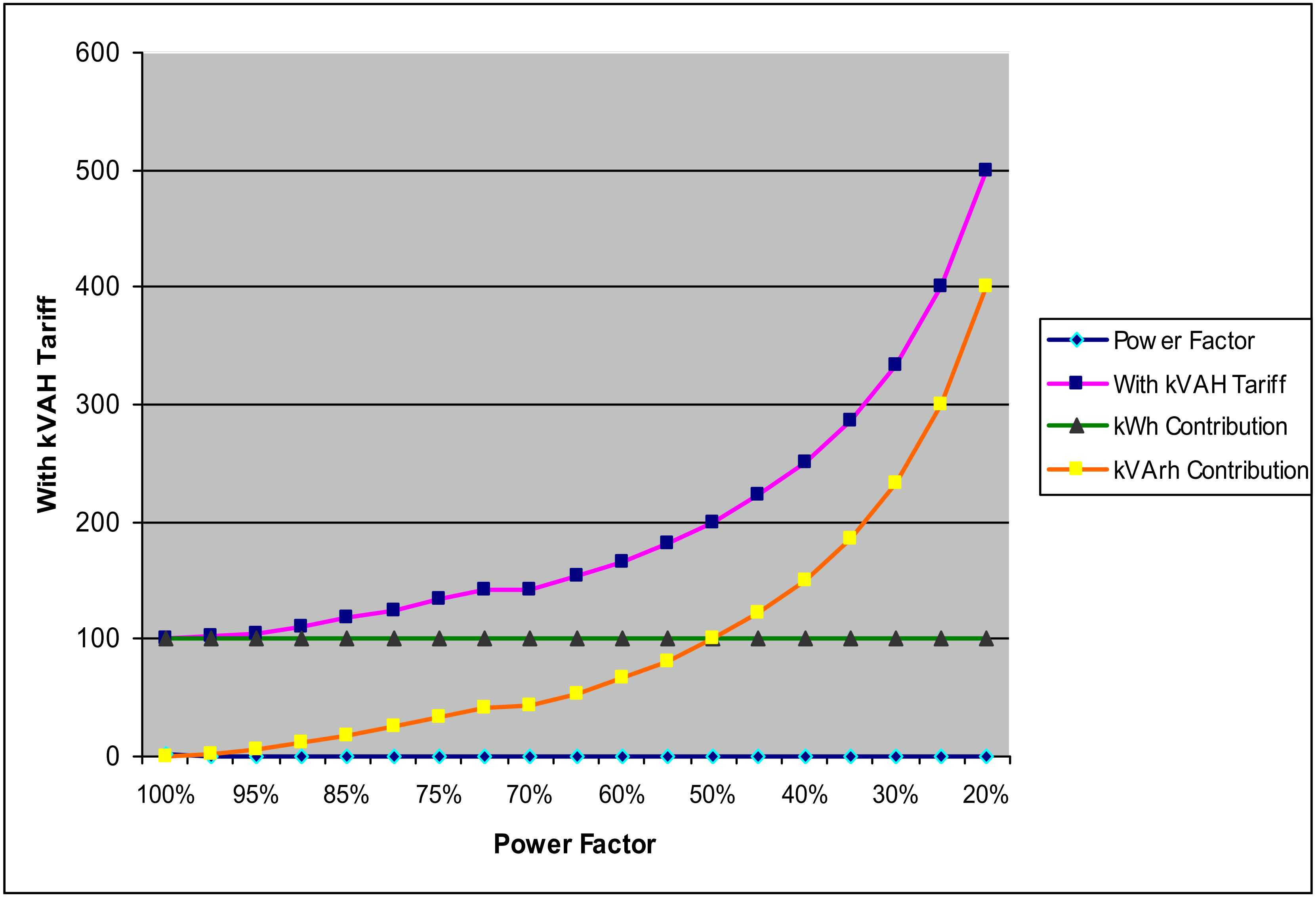

600
500
400
300
200
100
0
With kVAH Tariff
100%
95%
85%
75%
70%
60%
50%
40%
30%
20%
Power Factor
Pow er Factor
With kVAH Tariff
kWh Contribution
kVArh Contribution

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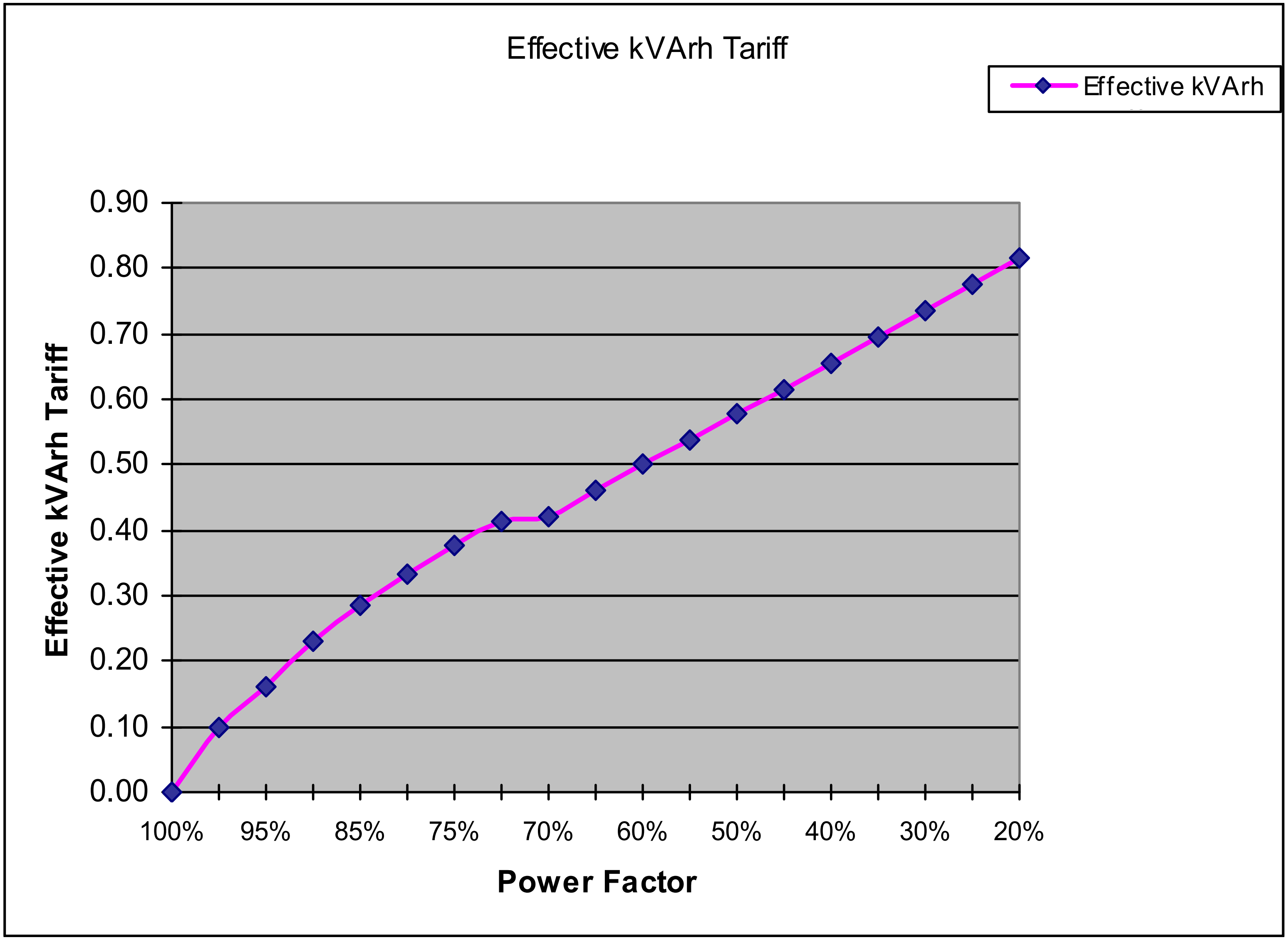

Effective kVArh Tariff
Effective kVArh
0.90
0.80
0.70
0.60
0.50
0.40
0.30
0.20
0.10
0.00
Effective kVArh Tariff
100%
95%
85%
75%
70%
60%
50%
40%
30%
20%
Power Factor

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Electricity Policy

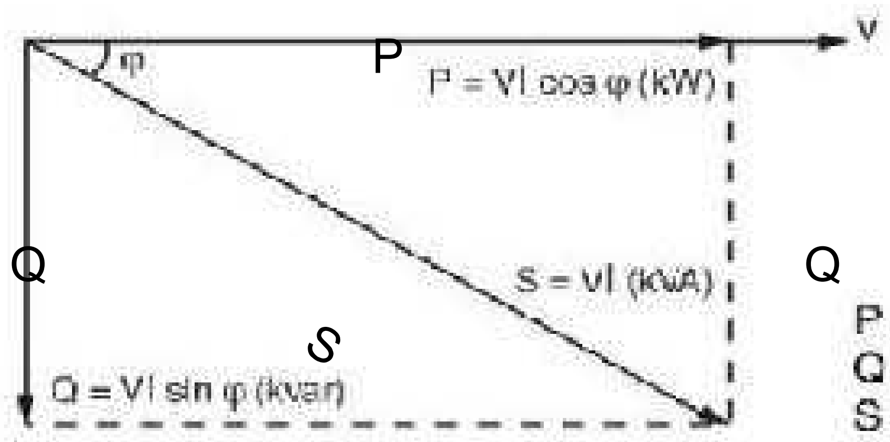
- If the Discoms do not depend on the grid for reactive power means, implementation of ;

  a) Energy conservation

  b) DSM measures

  c) Distributed generation

Thank You

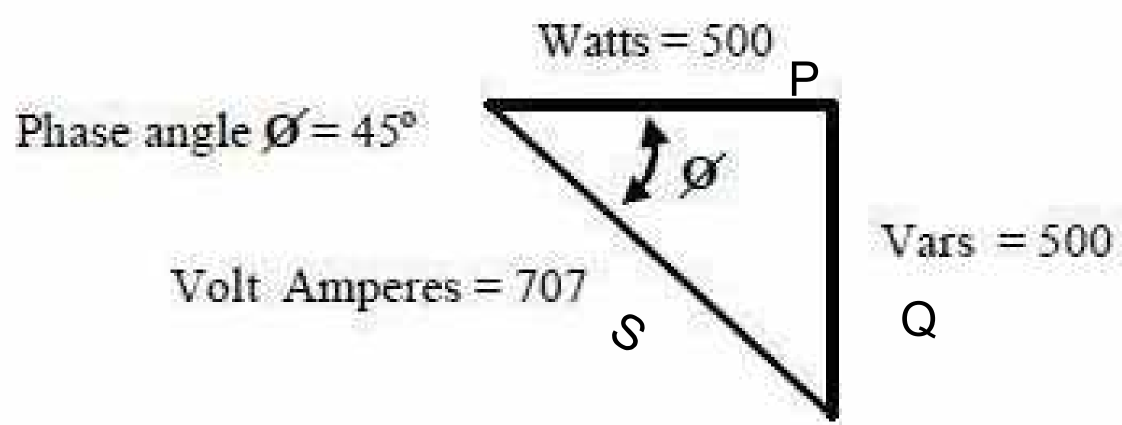


Power diagram

$S^2 = P^2 + Q^2$

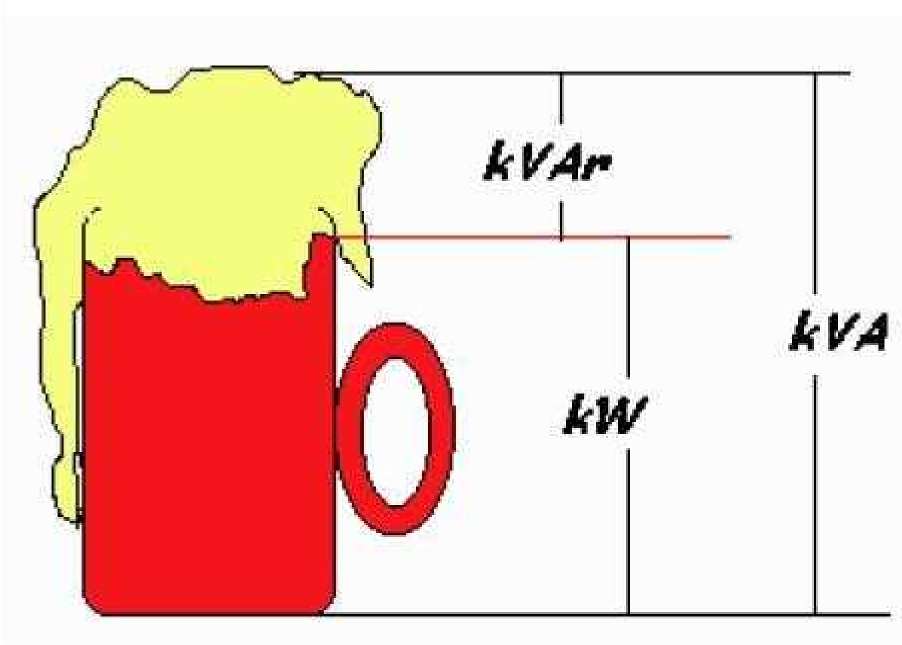
S = Sqrt of $(P^2 + Q^2)$

P = Active power
Q = Reactive power
S = Apparent power



Power Triangle

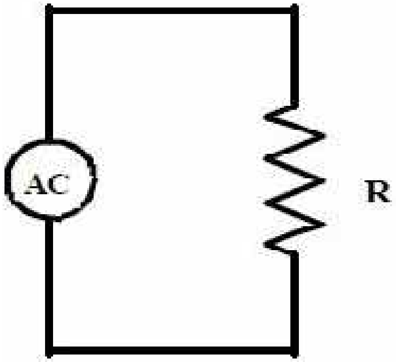
"Beer Mug analogy".



Power Factor = Active power/Apparent power = kW/kVA
= Active power/ (Active Power +Reactive Power)
= kW/(kW+kVAr)
= Beer/(Beer +Foam)

The more foam (higher kVAr) indicates low power factor and vice versa.

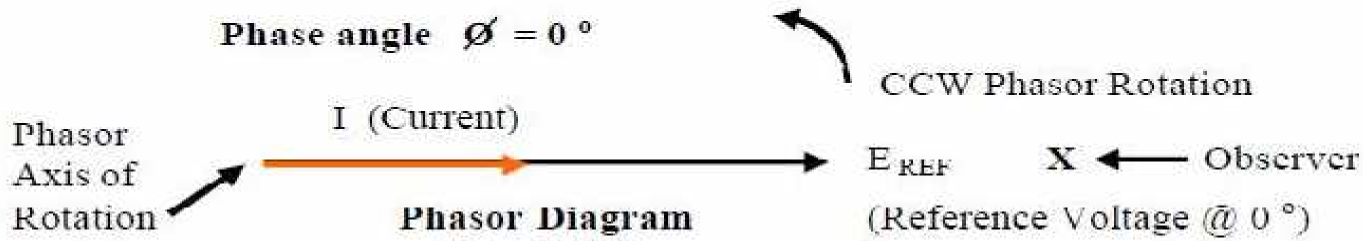
(In Electrical terms kW, kVA, and kVAr are vectors and we have to take the vector sum).



Circuit Diagram

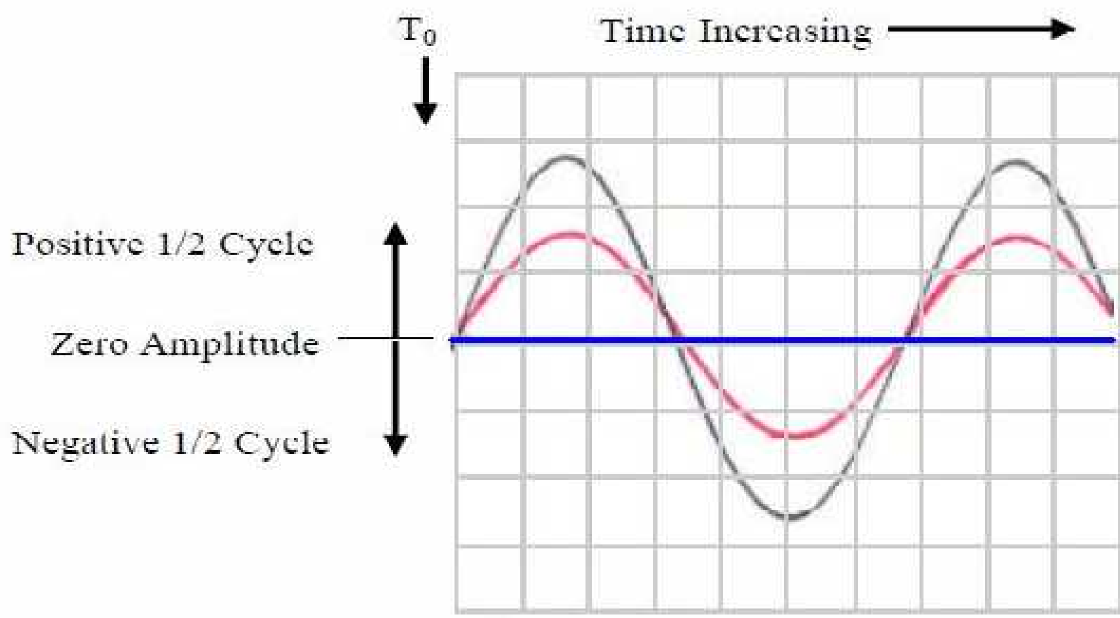
Voltage and Current are in-phase.

Phase angle $\varnothing = 0°$



Phasor Diagram
Current Red
Voltage Black

If the observer stands a point X above and watches the phasors rotate CCW, the voltage and current phasors will be in-phase with one another.



Red - Current
Black - Voltage

Sine Wave Relationship
Showing in-phase condition.

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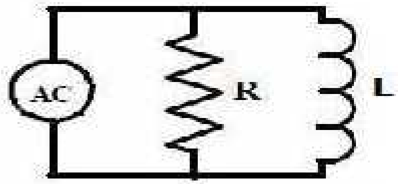
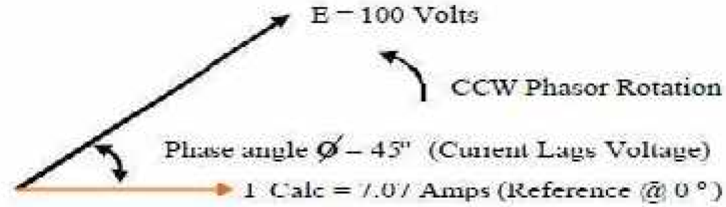
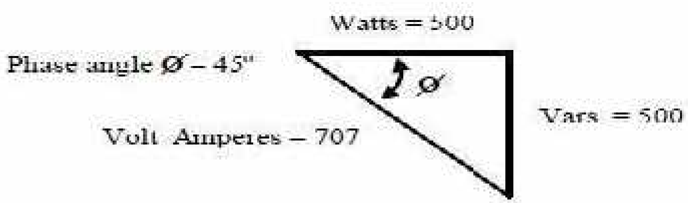


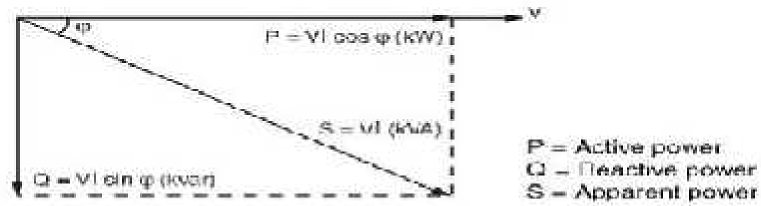
CIRCUIT DIAGRAM



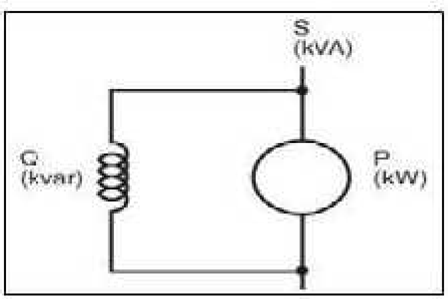
Phasor Diagram
Current Red
Voltage Black



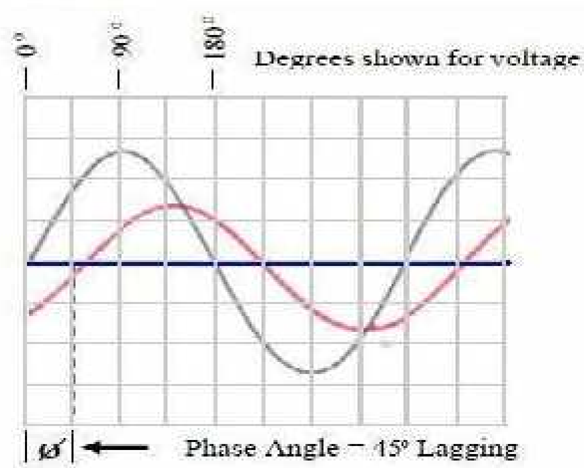
Power Triangle



Power diagram



An electric motor requires active power P and reactive power Q from the power system



Sine Wave Relationship
Red - Current

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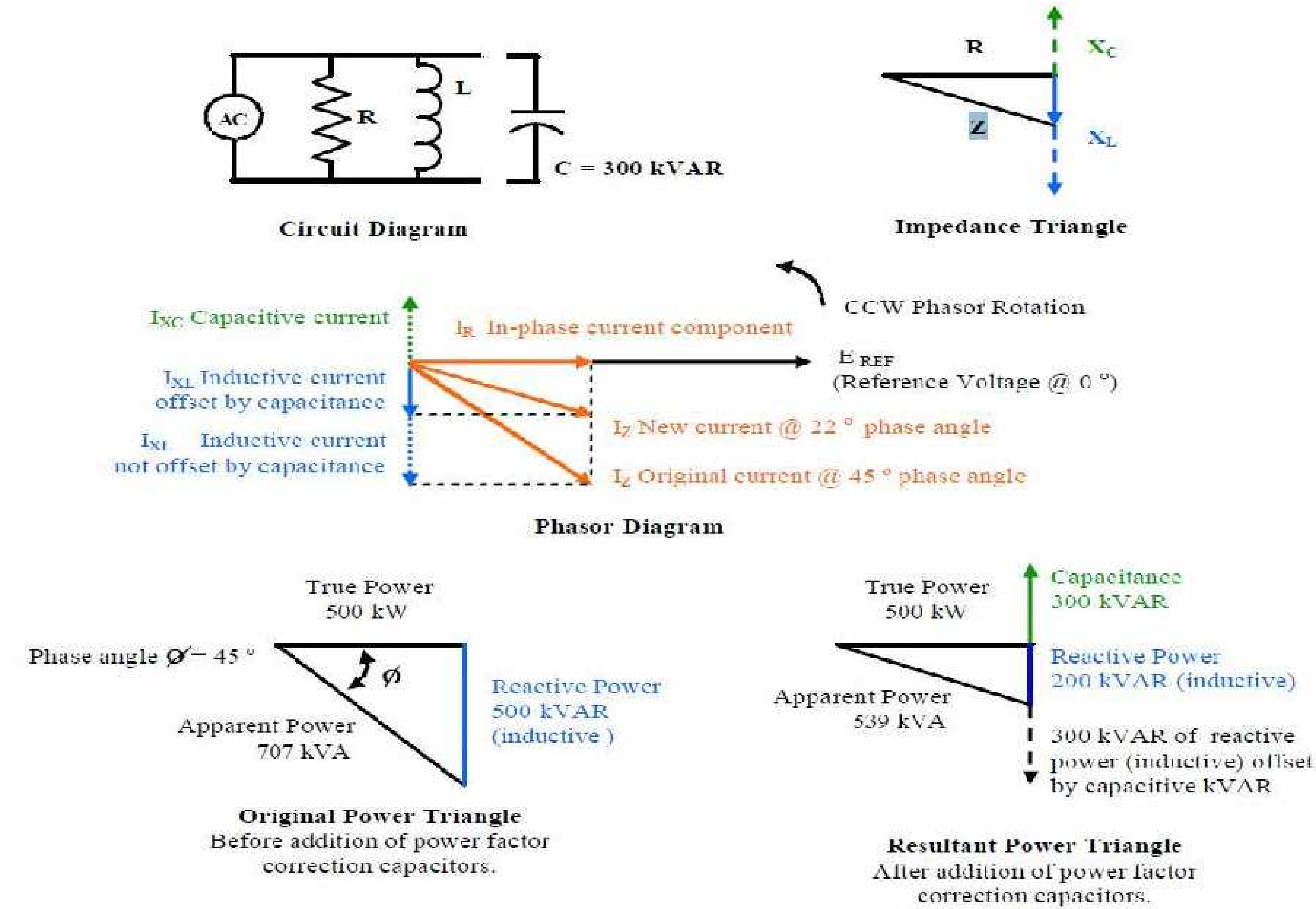

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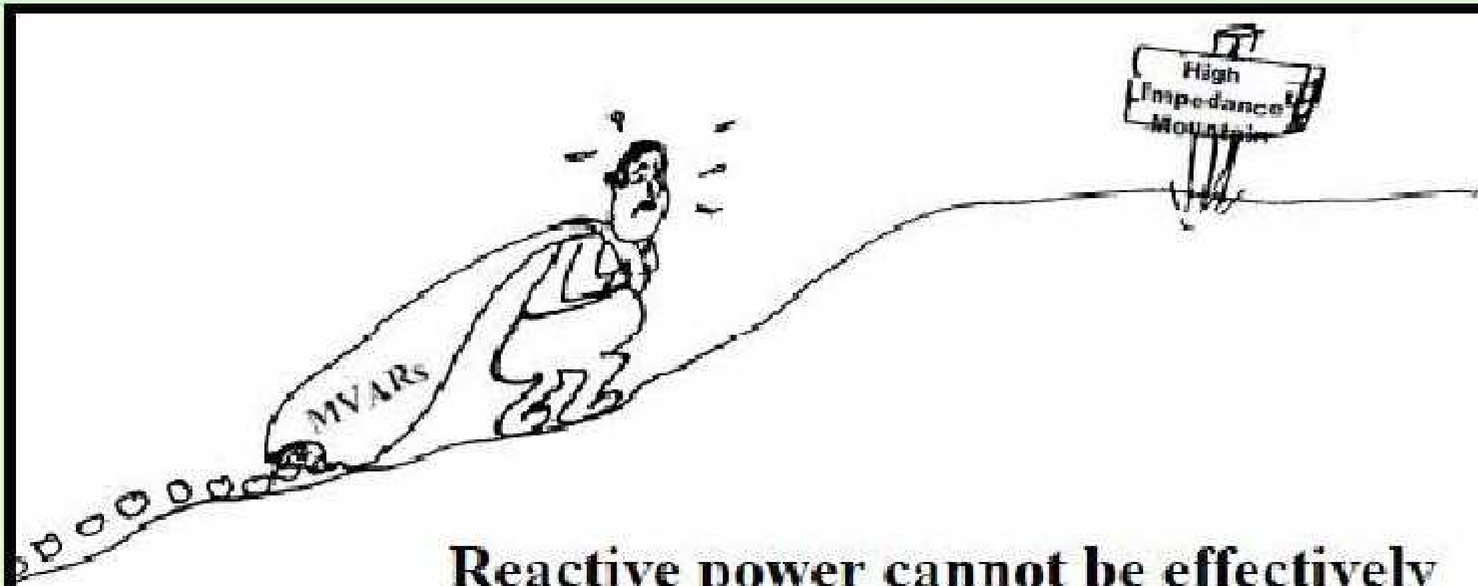
Transmitting Reactive Power



Reactive power cannot be effectively transmitted across long distances due to high I^2X losses.

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Equipment and appliances			cos φ	tan φ
Common induction motor	loaded at	0%	0.17	5.80
		25%	0.55	1.52
		50%	0.73	0.94
		75%	0.80	0.75
		100%	0.85	0.62
Incandescent lamps			1.0	0
Fluorescent lamps (uncompensated)			0.5	1.73
Fluorescent lamps (compensated)			0.93	0.39
Discharge lamps			0.4 to 0.6	2.29 to 1.33
Ovens using resistance elements			1.0	0
Induction heating ovens (compensated)			0.85	0.62
Dielectric type heating ovens			0.85	0.62
Resistance-type soldering machines			0.8 to 0.9	0.75 to 0.48
Fixed 1-phase arc-welding set			0.5	1.73
Arc-welding motor-generating set			0.7 to 0.9	1.02 to 0.48
Arc-welding transformer-rectifier set			0.7 to 0.8	1.02 to 0.75
Arc furnace			0.8	0.75

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