Overview of Power Factor Correction

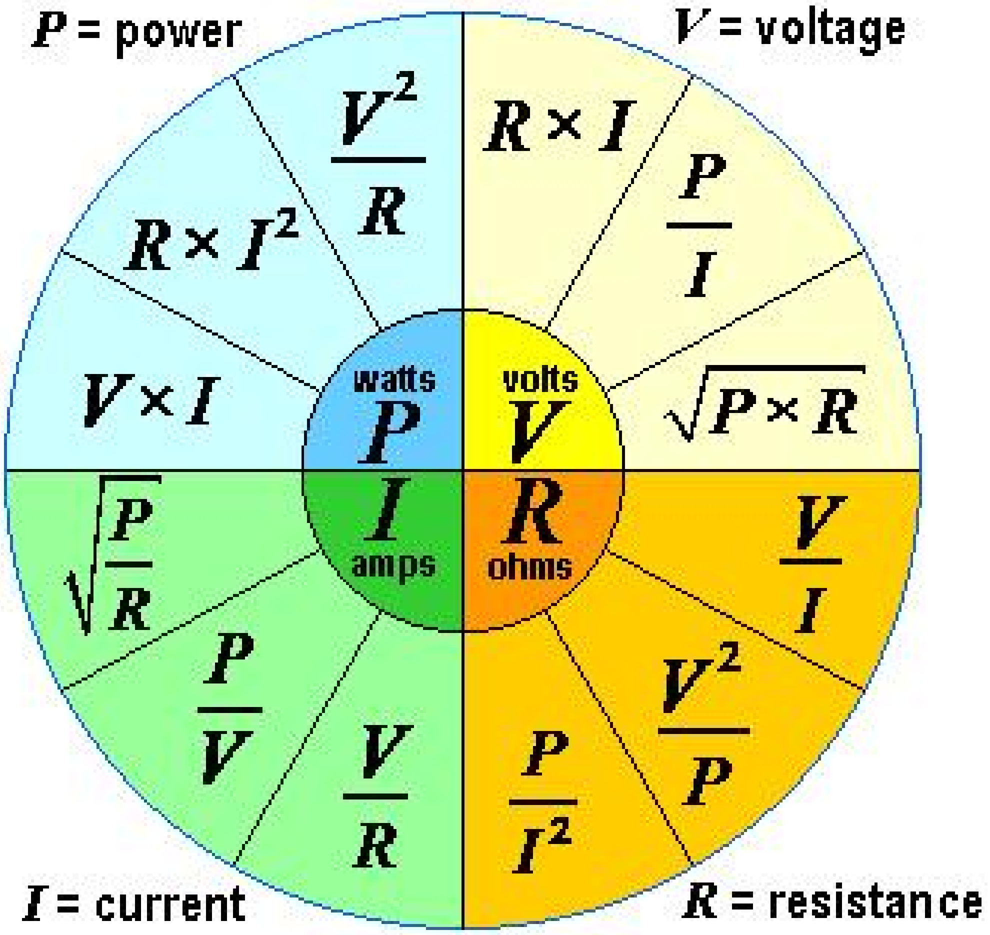
Presented to **Central Vermont Public Service** and
Efficiency Vermont

On November 5, 2007

Topics

- Basic Formulas (Ohm’s Law)
- Power Factor Fundamentals
- Improving Power Factor
- Utility Bill Analysis
- Sizing a Capacitor
- Capacitor Location
- Power Factor Correction Products

Basic Formulas (Ohm's Law)

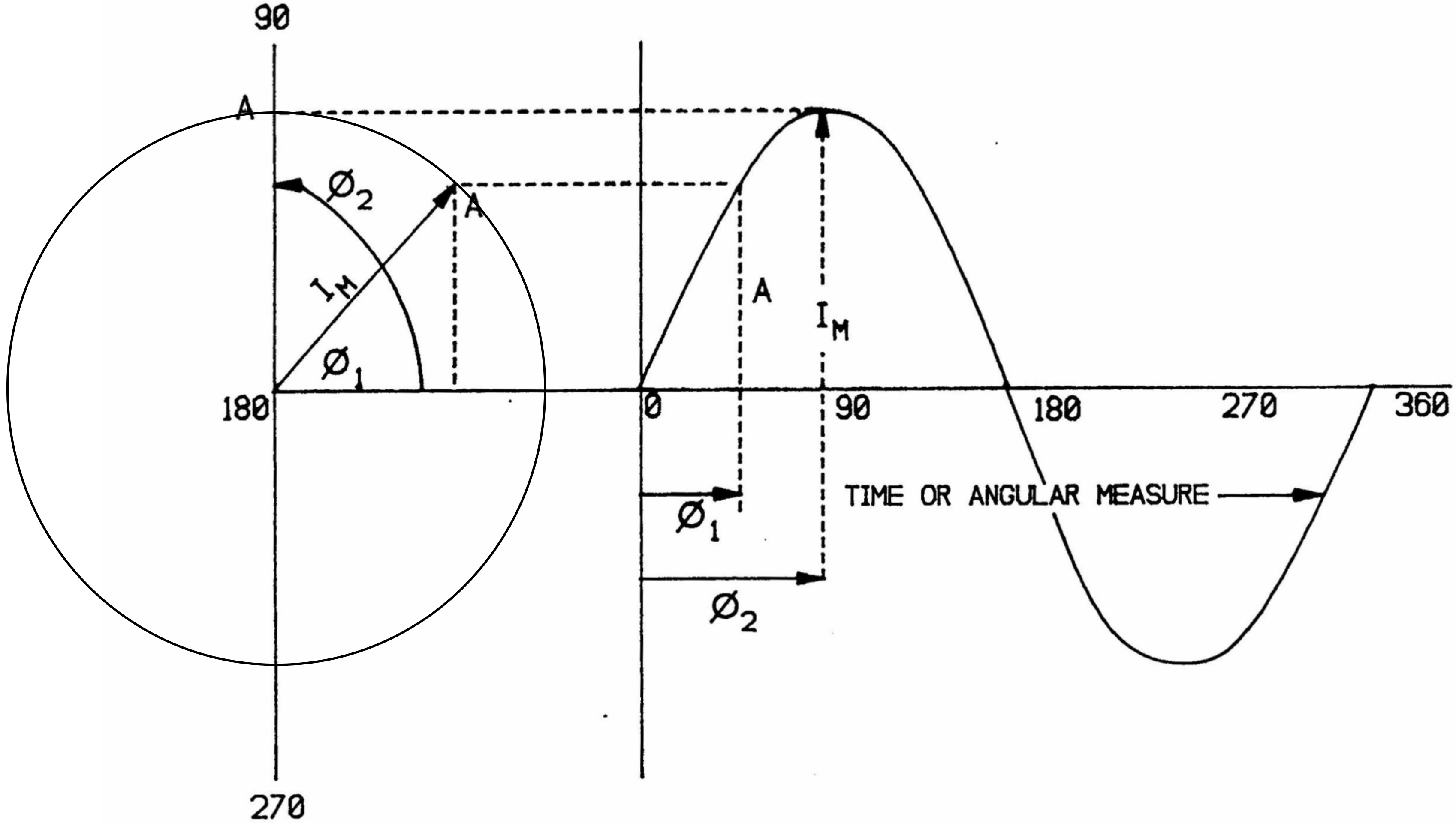


Power Factor Fundamentals

Terms to get you started –

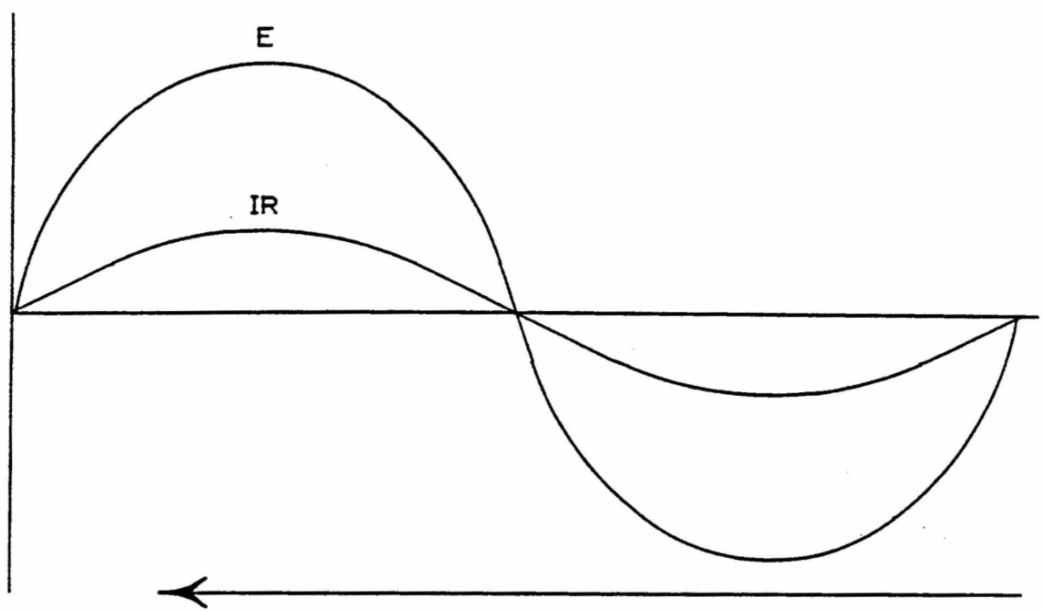
- Active Power
  - Measured in watts (normally shown as kW). Provides the “working” part of the power system. Producing heat, movement…
- Reactive Power
  - Measured in volt-ampere-reactive (normally shown as kVAr). Sustains the electromagnetic field. Provides no “working” part of the power system.
- Apparent Power
  - Measured in Volt-Ampere (normally shown as kVA). Provided both working and nonworking parts of the power system.

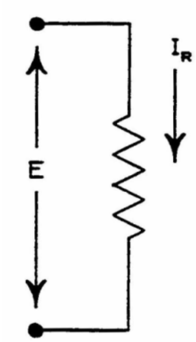
Power Factor Fundamentals

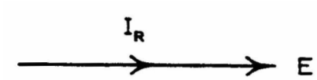


PROJECTION OF A REVOLVING VECTOR REPRESENTS A SINE WAVE

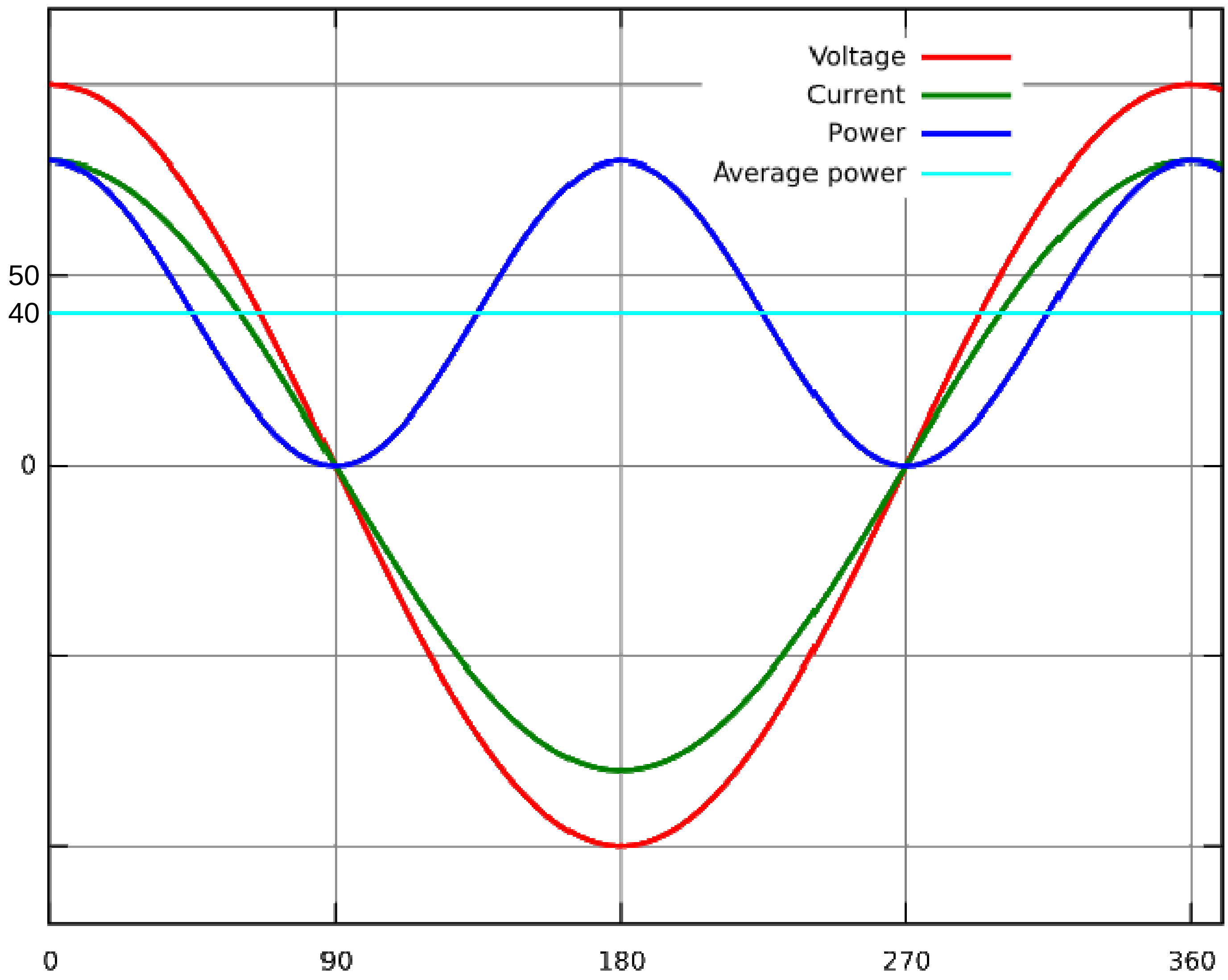
Power Factor Fundamentals







Power Factor Fundamentals



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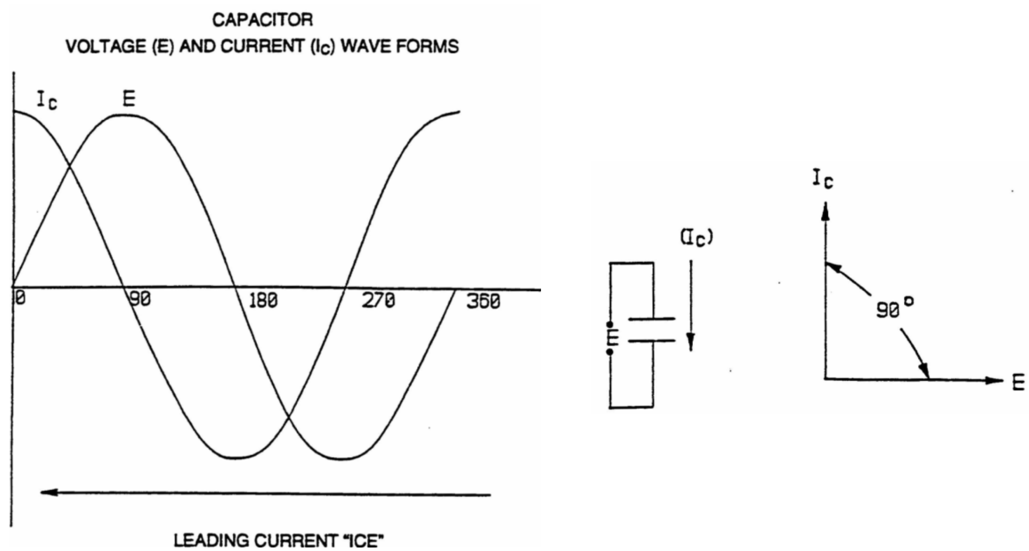

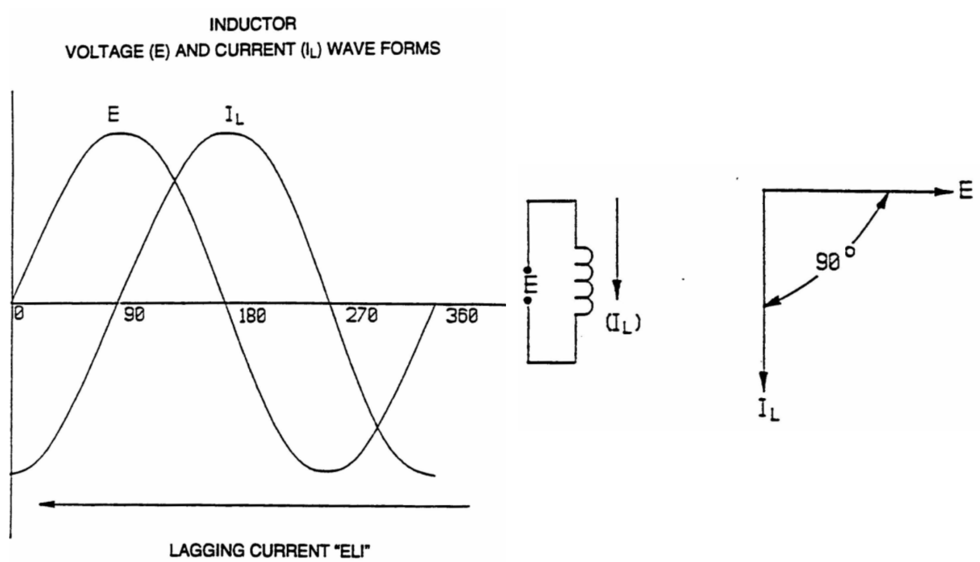

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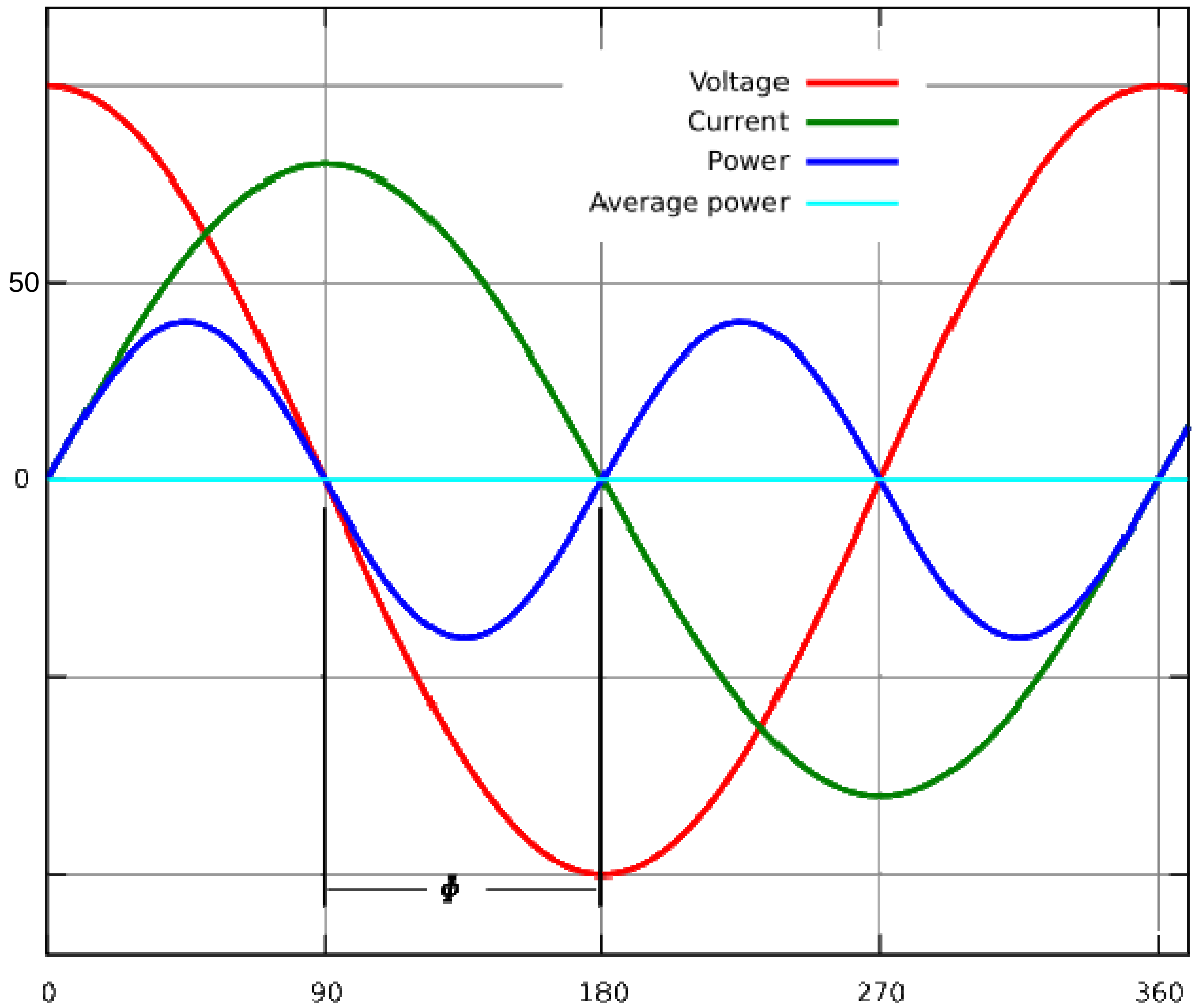

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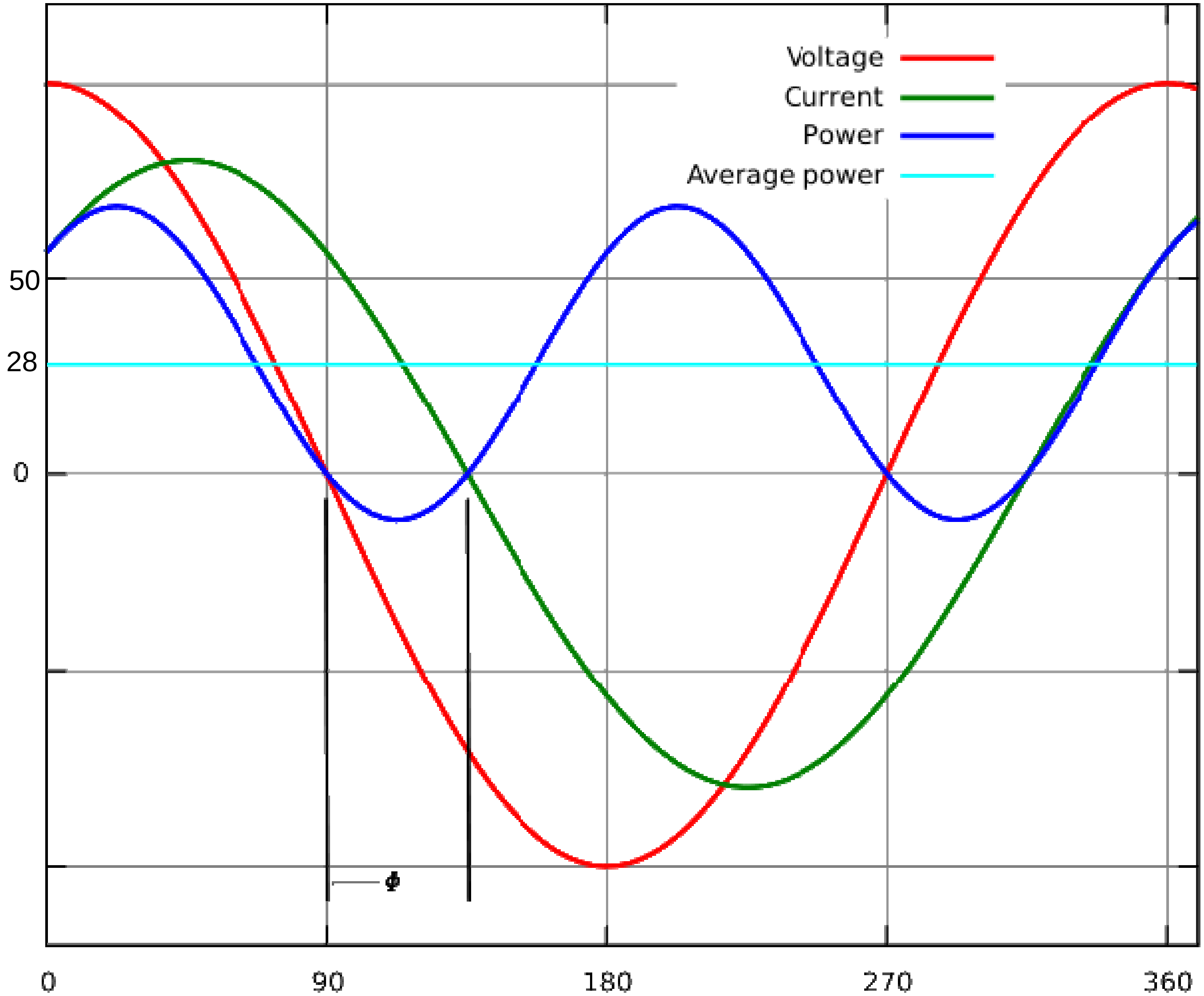

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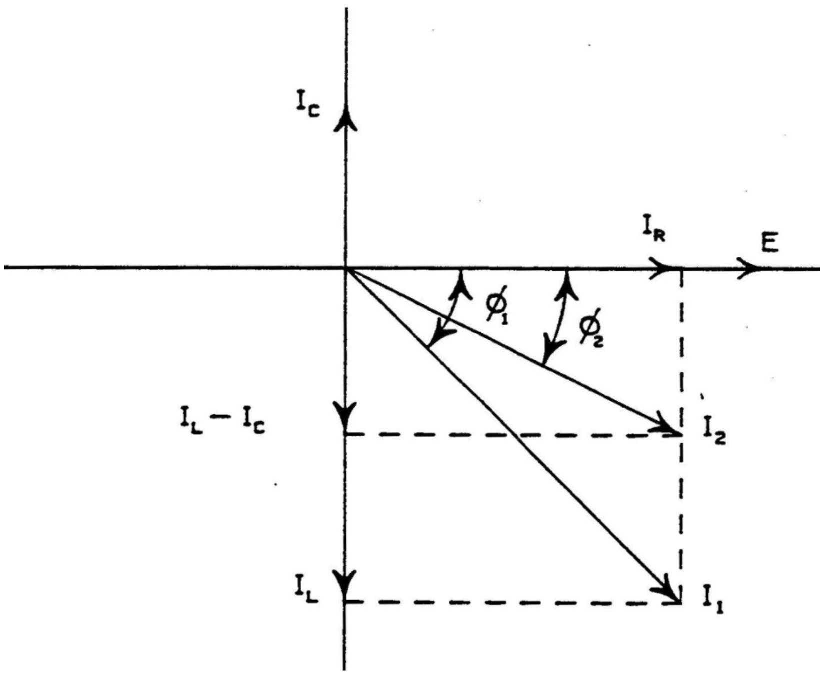
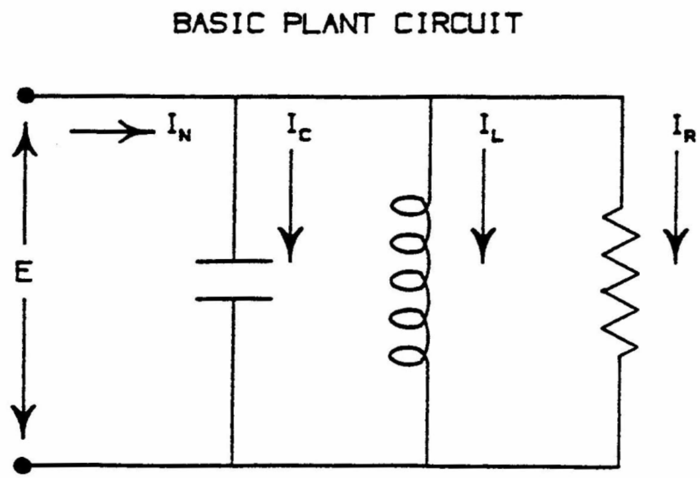


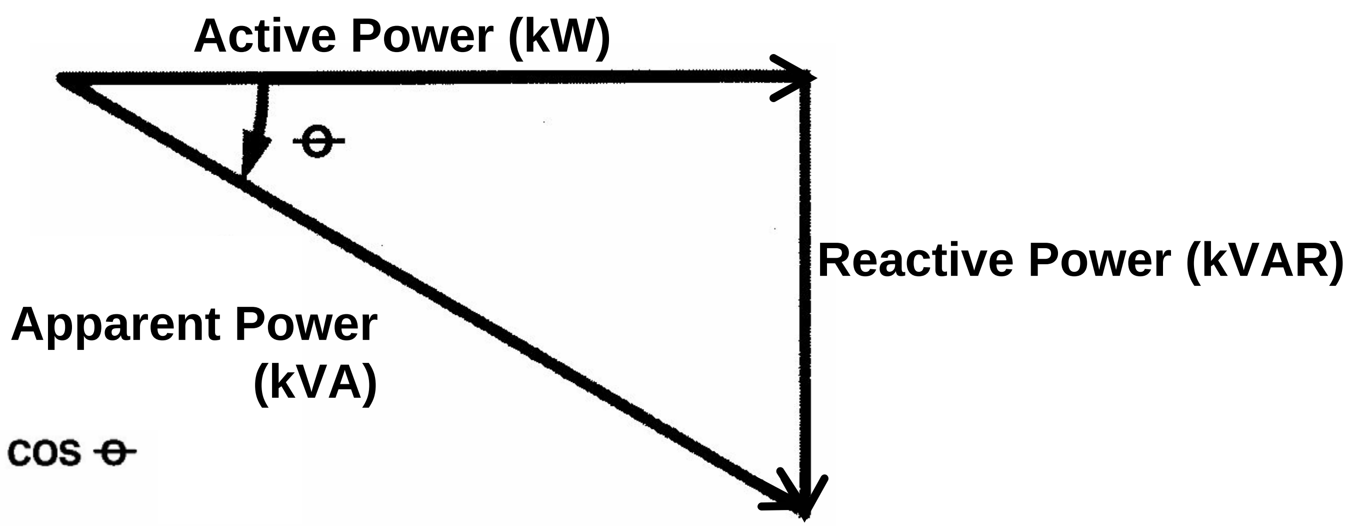


Power Factor Fundamentals

Power Factor Triangle

Power Factor (PF) = Active Power ÷ Apparent Power

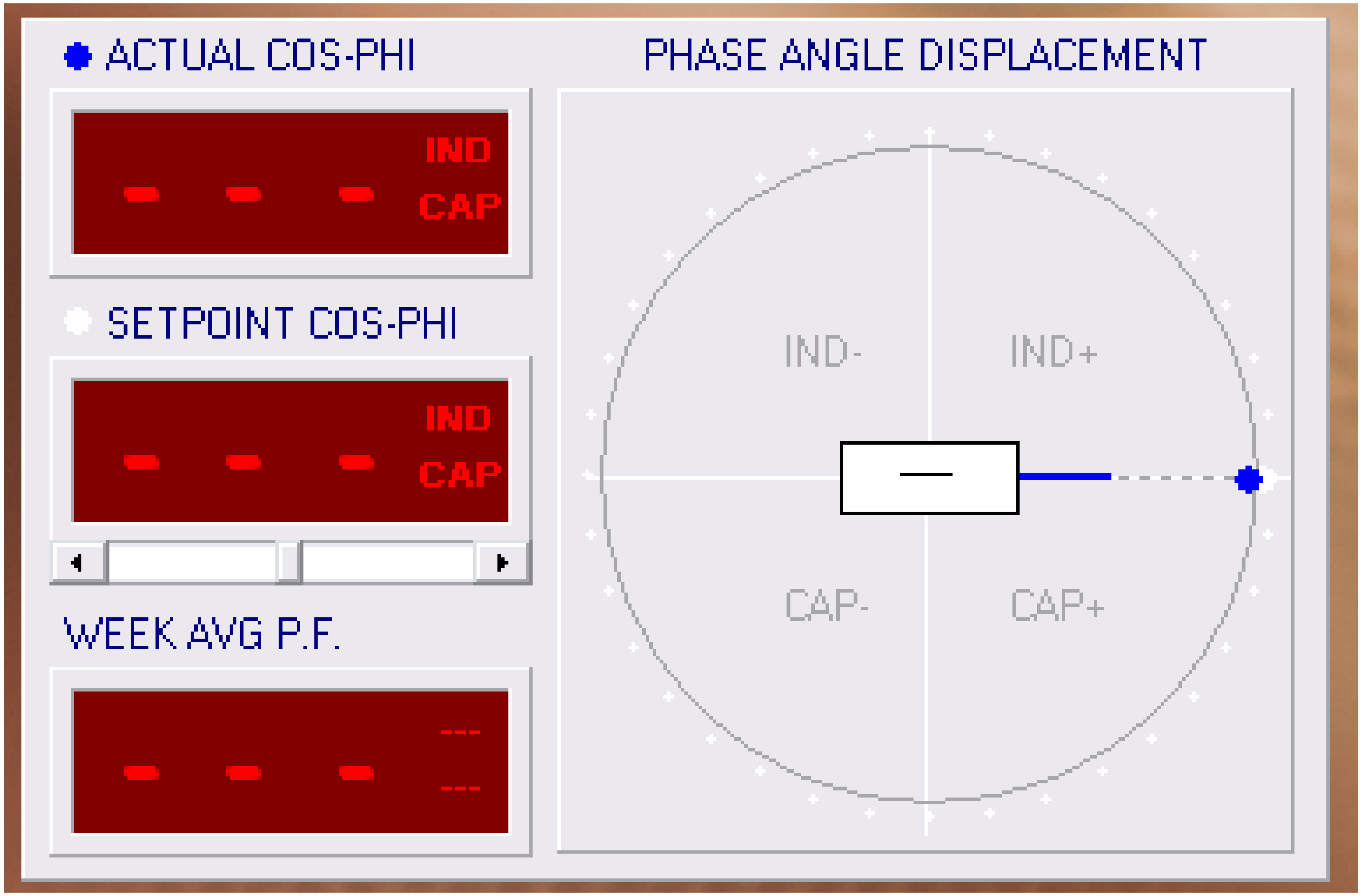
PF close to 1.0 means electrical power is being used effectively



$$PF = \frac{KW}{KVA} = \cos\theta$$

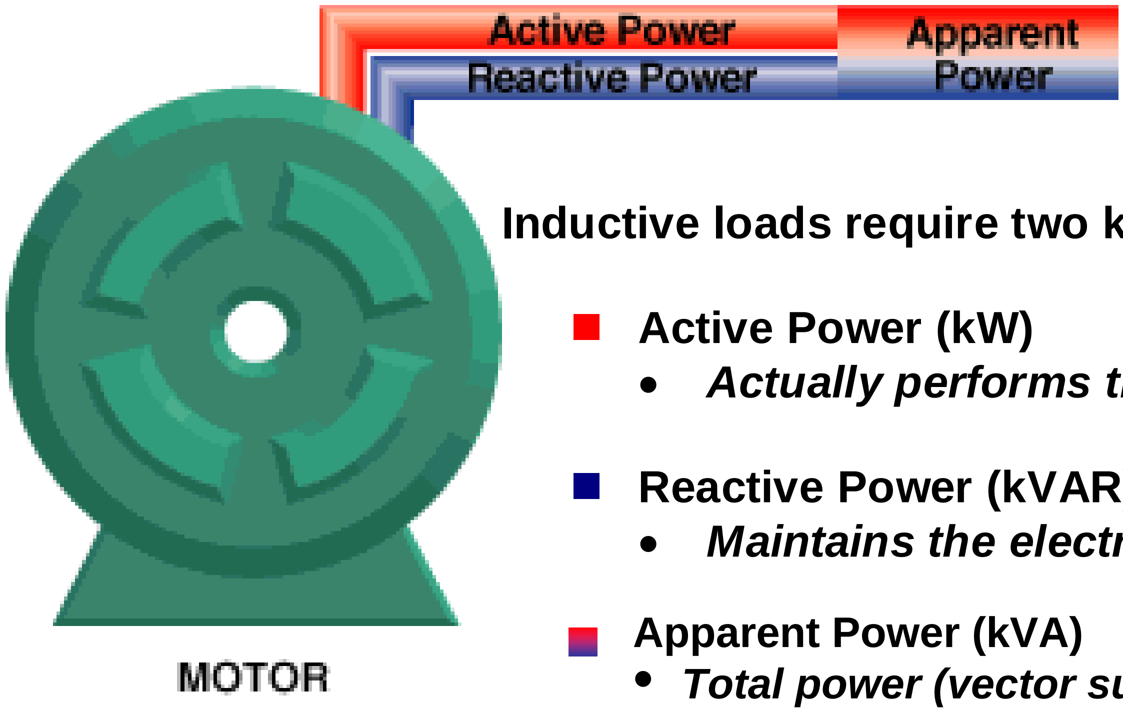
Capacitors provide reactive current and as a result reduce kVA and improve power factor

Power Factor Fundamentals



Power Factor Fundamentals

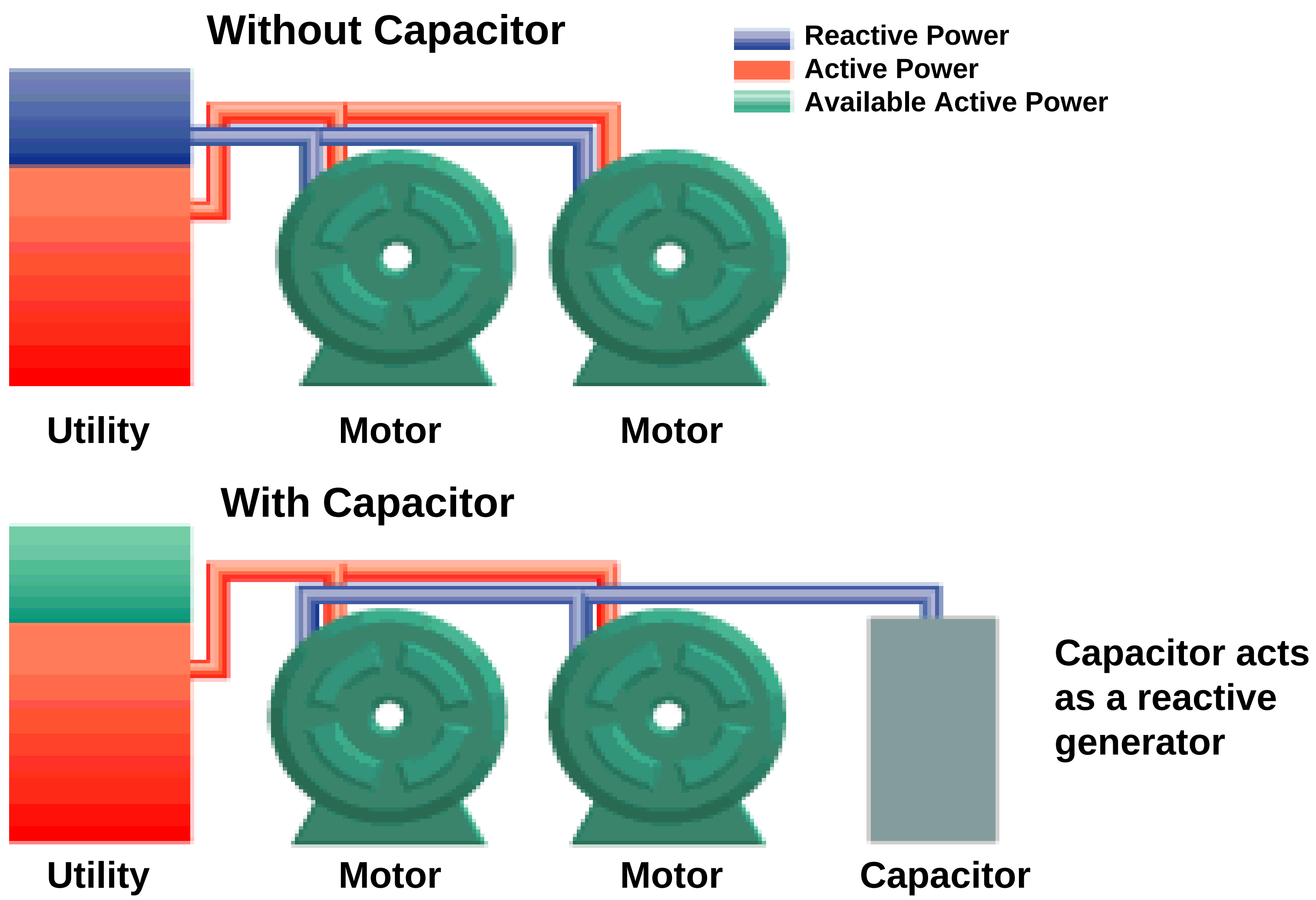
Power Factor is a measure of how effectively power is used



Inductive loads require two kinds of power to operate:

- **Active Power (kW)**
  - ***Actually performs the work***
- **Reactive Power (kVAR)**
  - ***Maintains the electro-magnetic field***
- **Apparent Power (kVA)**
  - ***Total power (vector sum of active and reactive power)***

Power Factor Fundamentals



Power Factor Fundamentals

Poor PF
0.70

Excellent PF
> 0.95

Power Factor Fundamentals

Power Factor of Typical Electrical Devices

Device	**Power Factor**
Incandescent Lights	0.99+
Baseboard Heat	0.99+
Fan Motor	0.90
Saw Mill Motor	0.50

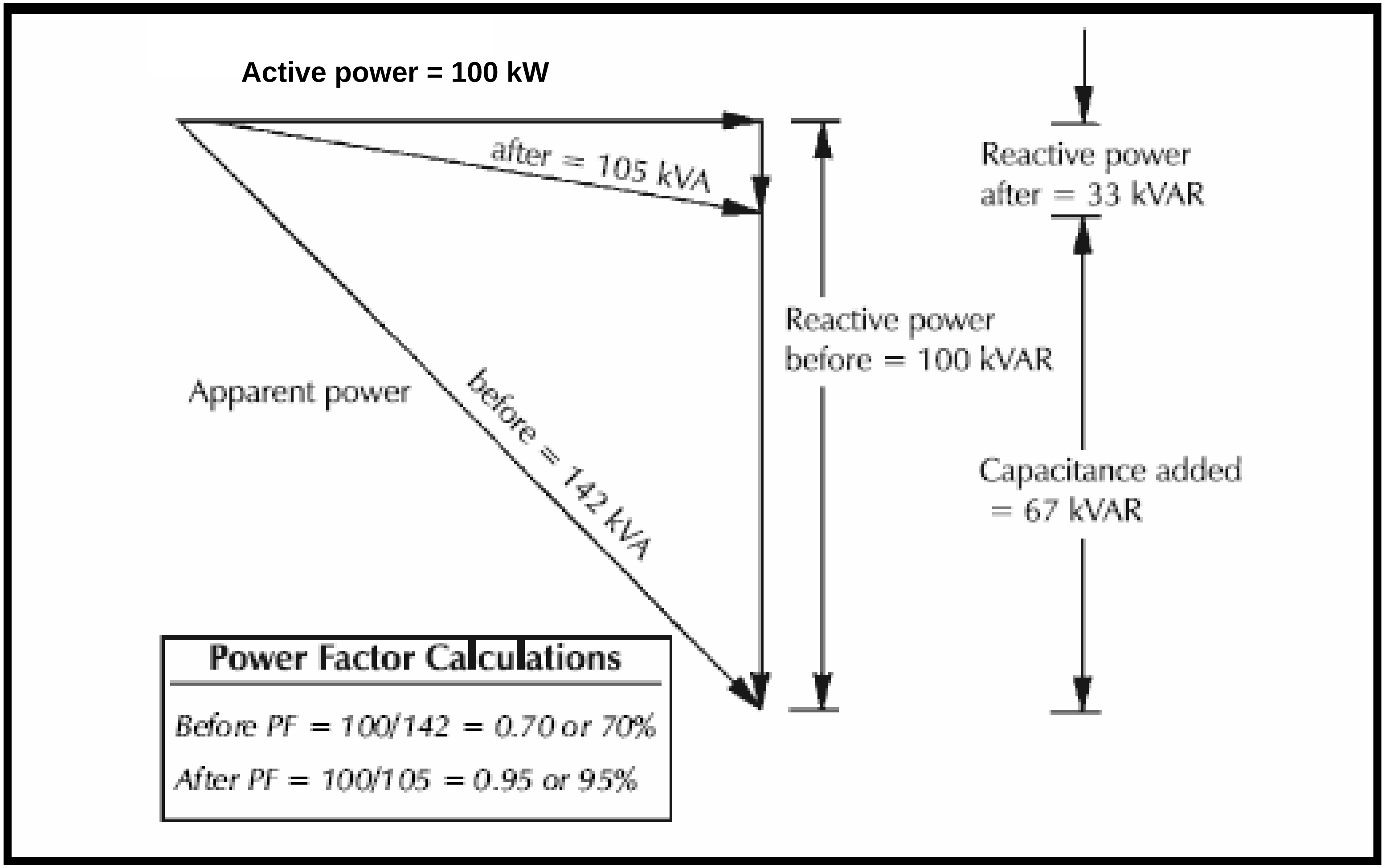
Low power factor typically results when motors are operated at significantly less than full load. Other examples of motors with low power factor:

- Conveyors
- Compressors
- Grinders
- Punch Presses

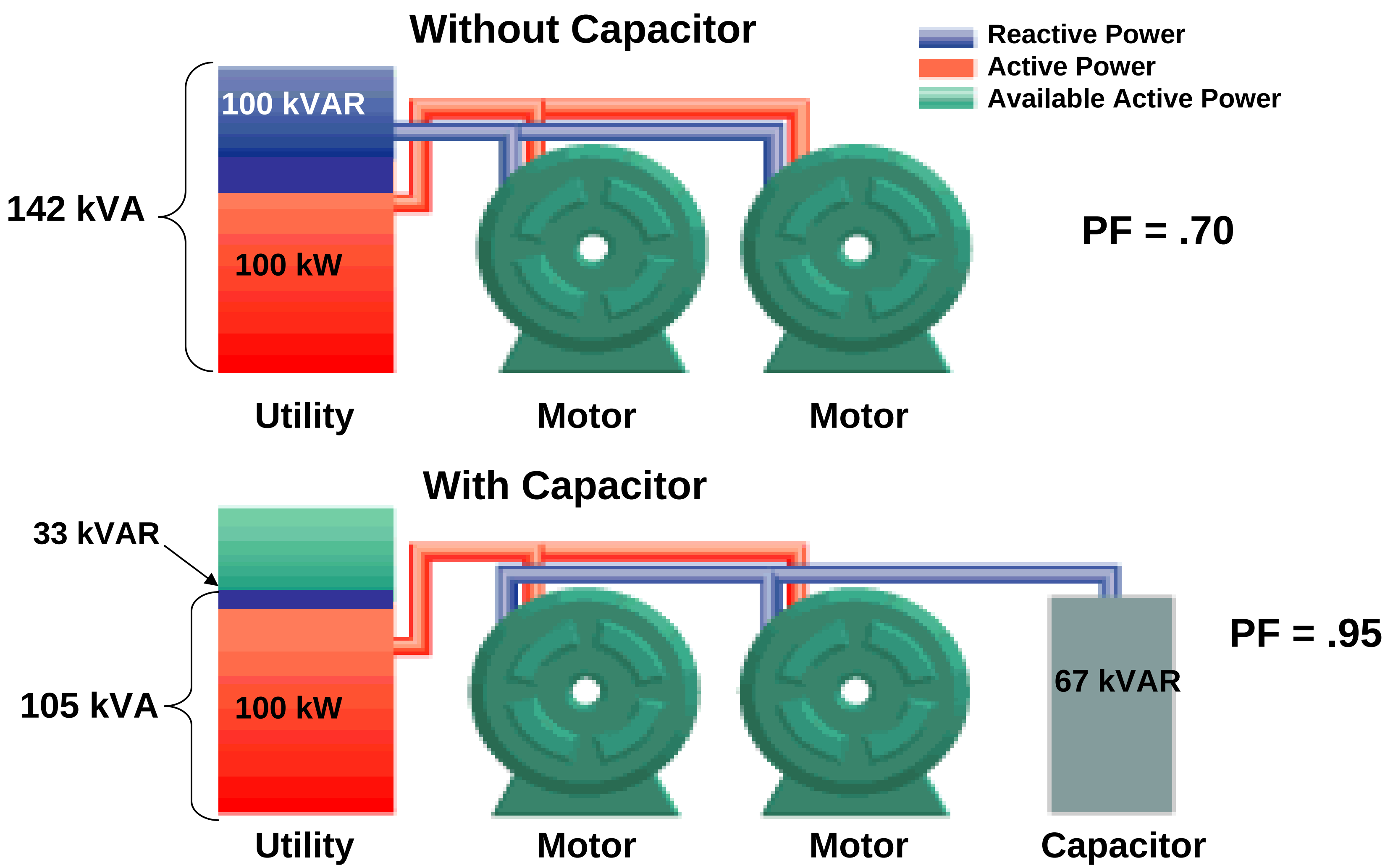
Improving Power Factor

Power Factor (PF) = Active Power ÷ Apparent Power

PF close to 1.0 means electrical power is being used effectively



Improving Power Factor



Improving Power Factor

Benefits of Applying Capacitors

- Elimination of Penalty Dollars
  - Improves your system power factor, reduces total KVA or KVA-Hours, saving you money on your electric power bill
- Additional Capacity in Electrical System
  - Releases system capacity by reducing KVA on transformers, saving you from making new capital investment to serve new electrical loads
- Reduction of I^2R Losses
  - Reduces system losses, saving energy costs and allowing your equipment to run cooler and more efficiently
- Improves Voltage on System
  - Allows motors to run more efficiently and cooler, improves their life and operation

Utility Bill Analysis

Types of Power and Typical Loads

Type of Power	Common Names	Typical Load/Component
KW – Kilowatt (Active Current)	Active Power Kilowatt/Watt Power Real Power Resistive Power	Resistor Incandescent Lights Toasters
KVAR = Kilovolt Amperes Reactive (Reactive Current)	Reactive Power Imaginary Power KVAR/VAR Power Inductive/Capacitive Power	Reactors/Inductors Capacitors
Most electrical loads usually need a combination of both active and reactive current.		
KVA – Kilovolt Amperes (Active + Reactive)	Apparent Power Complex Power Total Power KVA/VA Power	All industrial loads: -Motors -Welders -Variable Speed Drives -Lighting Loads

Utility Bill Analysis

Basic Types Of Utility Billing Protocols

Billing Protocol	**Concept**	**How Capacitors Reduce Cost**
KVA	Utility bills for every Amp of current, both active and reactive. Typically based on peak current.	Capacitors reduce reactive current and therefore peak current.
KW demand with power-factor adjustment	Utility bills for KW demand plus a surcharge for low power factor, for example: below 95%, below 85%, etc.	Capacitors increase power factor to minimum required, eliminating surcharge. Sometimes a credit for high power factor.
KW demand with reactive demand charge	Utility bills for KW demand plus a surcharge for excessive reactive demand.	Capacitors reduce reactive demand, eliminating surcharge.

Utility Bill Analysis

Here are savings of a Detroit Edison customer after improving PF to >85. The power triangle started out at 812 KW, 1160 KVA and 828 KVAR. The customer installed capacitor banks totaling 410 KVAr. The final power triangle numbers were 812 KW, 913 KVA and 418 KVAR.

What does that mean in dollars for the customer:

The customer, doing the same amount of work but now with capacitors installed, has eliminated a $650.00 monthly penalty. This would translate in to an annual savings of $7,800.00. The capacitors and installation project totaled $7,351.00. ROI for the project was less than 12 months.

How does this benefit the electrical system:

The utility has to generate 247 less kVA (1160-913=247). The customer has also unloaded his transformer of 247 kVA, which will allow for additional loads in the future without having to increase the transformer size.

Utility Bill Analysis

A utility bill shows an average power factor of 0.72 with an **average KW** of 627. How much KVAR is required to improve power factor to 0.95?

Using a PFC Multiplier Table (next slide)

1. Locate 0.72 (original PF) in column 1.
2. Read across desired PF to 0.95 column, intersect at 0.635 multiplier
3. Multiply 627 (**average KW**) by 0.635 = 398 KVAR
4. Install 400 KVAR to improve PF to 95%

Original Power Factor (%)	Desired Power Factor (%) 80	85	90	91	92	93	94	95	96	97	98	99	100
68	0.328	0.459	0.594	0.623	0.652	0.683	0.715	0.750	0.787	0.828	0.875	0.936	1.078
69	0.299	0.429	0.565	0.593	0.623	0.654	0.686	0.720	0.757	0.798	0.846	0.907	1.049
70	0.270	0.400	0.536	0.565	0.594	0.625	0.657	0.692	0.729	0.770	0.817	0.878	1.020
71	0.242	0.372	0.508	0.536	0.566	0.597	0.629	0.663	0.700	0.741	0.789	0.849	0.992
72	0.214	0.344	0.480	0.508	0.538	0.569	0.601	**0.635**	0.672	0.713	0.761	0.821	0.964
73	0.186	0.316	0.452	0.481	0.510	0.541	0.573	0.608	0.645	0.686	0.733	0.794	0.936
74	0.159	0.289	0.425	0.453	0.483	0.514	0.546	0.580	0.617	0.658	0.706	0.766	0.909
75	0.132	0.262	0.398	0.426	0.456	0.487	0.519	0.553	0.590	0.631	0.679	0.739	0.882
76	0.105	0.235	0.371	0.400	0.429	0.460	0.492	0.526	0.563	0.605	0.652	0.713	0.855
77	0.079	0.209	0.344	0.373	0.403	0.433	0.466	0.500	0.537	0.578	0.626	0.686	0.829
78	0.052	0.183	0.318	0.347	0.376	0.407	0.439	0.474	0.511	0.552	0.599	0.660	0.802
79	0.026	0.156	0.292	0.320	0.350	0.381	0.413	0.447	0.484	0.525	0.573	0.634	0.776
80	0.000	0.130	0.266	0.294	0.324	0.355	0.387	0.421	0.458	0.499	0.547	0.608	0.750
81		0.104	0.240	0.268	0.298	0.329	0.361	0.395	0.432	0.473	0.521	0.581	0.724
82		0.078	0.214	0.242	0.272	0.303	0.335	0.369	0.406	0.447	0.495	0.556	0.698
83		0.052	0.188	0.216	0.246	0.277	0.309	0.343	0.380	0.421	0.469	0.530	0.672
84		0.026	0.162	0.190	0.220	0.251	0.283	0.317	0.354	0.395	0.443	0.503	0.646
85		0.000	0.135	0.164	0.194	0.225	0.257	0.291	0.328	0.369	0.417	0.477	0.620

Utility Bill Analysis

Try this one yourself-

A utility bill shows an average power factor of 0.79 with an "**average kW"** of 865. How much KVAR is required to improve power factor to 0.95?

The average kW can be calculated in a few different ways depending on the information available on the utility bill.

Sizing a Capacitor

Determine:

- HP
- Motor Type (Frame, Design)
- RPMs

Use the following table to determine KVAR

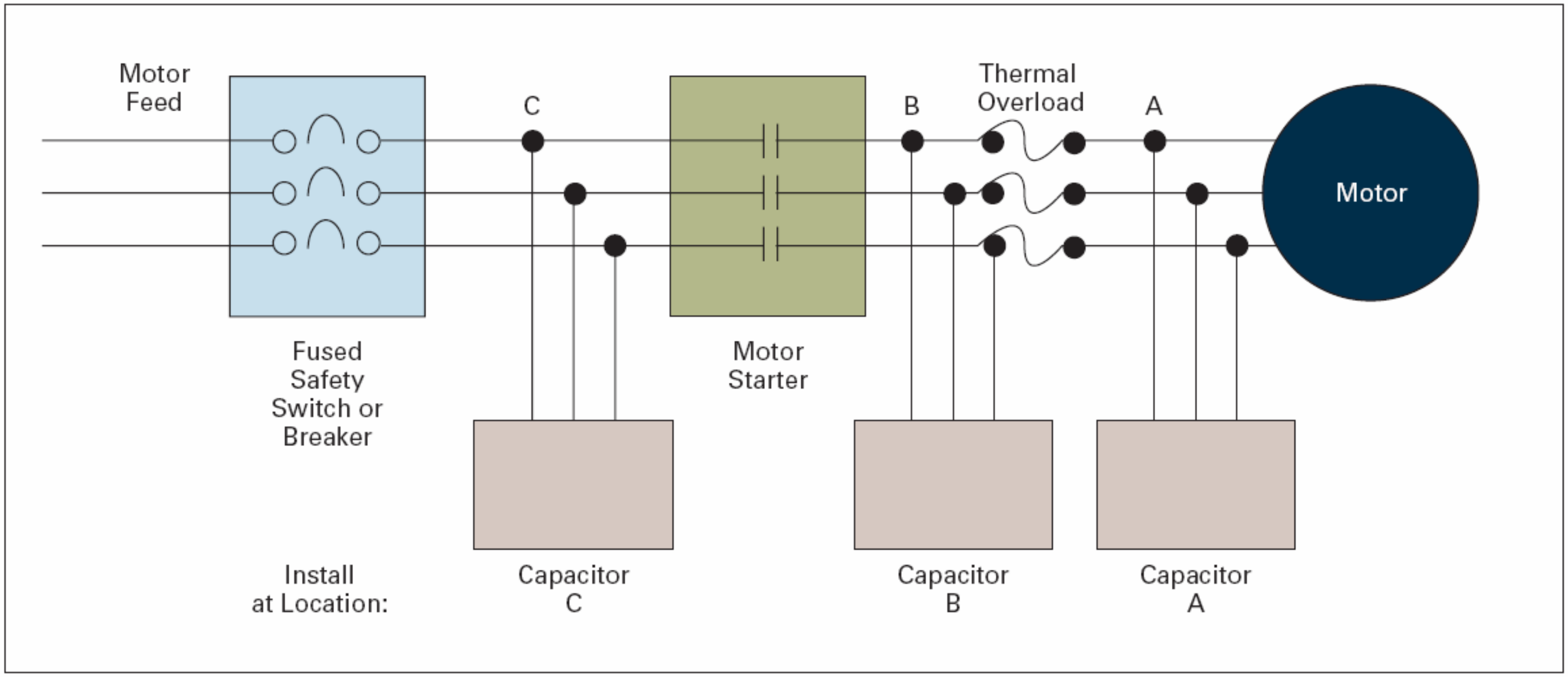
The following table shows “suggested maximum capacitor ratings” to raise full load PF to approximately 95%

Sizing a Capacitor

Induction Motor Horsepower Rating	No. of Poles and Nominal Motor Speed in RPM											
	2 3600 RPM		4 1800 RPM		6 1200 RPM		8 900 RPM		10 720 RPM		12 600 RPM	
	Capacitor KVAR	Current Reduction %	Capacitor KVAR	Current Reduction %	Capacitor KVAR	Current Reduction %	Capacitor KVAR	Current Reduction %	Capacitor KVAR	Current Reduction %	Capacitor KVAR	Current Reduction %
2	1	14	1	24	1.5	30	2	42	2	40	3	50
3	1.5	14	1.5	23	2	28	3	38	3	40	4	49
5	2	14	2.5	22	3	26	4	31	4	40	5	49
7.5	2.5	14	3	20	4	21	5	28	5	38	6	45
10	4	14	4	18	5	21	6	27	7.5	36	8	38
15	5	12	5	18	6	20	7.5	24	8	32	10	34
20	6	12	6	17	7.5	19	9	23	10	29	12.5	30
25	7.5	12	7.5	17	8	19	10	23	12.5	25	17.5	30
30	8	11	8	16	10	19	15	22	15	24	20	30
40	12.5	12	15	16	15	19	17.5	21	20	24	25	30
50	15	12	17.5	15	20	19	22.5	21	22.5	24	30	30
60	17.5	12	20	15	22.5	17	25	20	30	22	35	28
75	20	12	25	14	25	15	30	17	35	21	40	19
100	22.5	11	30	14	30	12	35	16	40	15	45	17
125	25	10	35	12	35	12	40	14	45	15	50	17
150	30	10	40	12	40	12	50	14	50	13	60	17
200	35	10	50	11	50	11	70	14	70	13	90	17
250	40	11	60	10	60	10	80	13	90	13	100	17
300	45	11	70	10	75	12	100	14	100	13	120	17
350	50	12	75	8	90	12	120	13	120	13	135	15
400	75	10	80	8	100	12	130	13	140	13	150	15
450	80	8	90	8	120	10	140	12	168	14	160	15
500	100	8	120	9	150	12	160	12	180	13	180	15

* For use with 3-phase, 60 hertz NEMA Classification B Motors to raise full load power factor to approximately 95%

Capacitor Locations



Location A: New motor installation where overloads can be adjusted to reduced amp draw. Existing motors when unable to place connection between starter and overloads (overloads must be sized according to new amp draw).

Location B: Normally used for most motor applications

Location C: Used when motors are jogged, plugged, reversed; for multi-speed motors, or reduced-voltage start motors. Also motors that start frequently.

Products

Power Factor Correction Capacitors

***CALMOUNT*® brand capacitor series**
Correct poor power factor at the load

Products

Power Factor Correction Capacitors

Capacitor Characteristic	Myron Zucker Advantages/Benefits
Cell Casing	Industrial grade metal cell case, 20-year life
Cell Phases	3-phase cell
Pressure interrupter	Open, safe, non-flammable event
Cell Contents	Dry
Replaceable Cells	Individual capacitor cells easy to replace, if necessary. Key feature for MRO market.
Power Termination	Threaded stud, secure
Loss-of-kVAR Signal	Patented signal (CelTel®)
Fusing	All capacitors are fused
Conduit entry	Bottom or back conduit entry. Easier to wire; requires less material
Enclosure design	Lift-off cover, open on 4 sides around wire termination Easier, faster to maintain
NEMA enclosure	NEMA 12-type standard

Products

Power Factor Correction Capacitors

•Multical® – Corrects up to 4 motors with single capacitor assembly

•Traymount® -Open-style capacitor for Motor Control Center

Products

Power Factor Correction Capacitors

- •Capacibank®
- •Autocapacibank ™

Distribution center, service entrance

Benefits & Features

- Low Voltage: 240, 480, 600 Volt –other ratings available
- U.L. Listed
- Patented CelTel ® for loss-of-capacitance signal and monitoring system for auto-disconnect feature
- Broadest PFCC product offering in the industry

People Who Specify and/or Purchase PFCCs

- End User (*How is your power factor / power quality?)*
  - Plant Engineers
  - Maintenance Supervisors
  - New Construction
  - Primary Utility User
    - Refrigeration & Lighting
    - Waste Water Treatment Facilities
    - Plastics Extrusion Plants
    - Automotive Plants
    - Plating Plants
- OEMs – Controls Engineers
- Electrical Motor Suppliers
- Electrical Distributors
- A & E firms
- Utility Account Reps

What Does Poor Factor Mean For….

The Supplier

- Ineffective use of transmission lines
- Ineffective use of generators
- Loss of productivity since more resources (coal, water, etc.) is required to produce the same amount of real power used.

The User

- Increase of thermal loss in the installed devices (I^2R)
- Larger capacity supply line, transformer, power usage
- Increase cost of use for electricity

Still need help?

Just call Paul!

(401) 473-8516 or paul_ecs@msn.com

If general information is provided:

- We will recommend unit rating and style

If One-Line diagram is provided

- We will recommend location of capacitors

If electrical bills are provided

- We will calculate monthly power cost savings and payback time of recommended products

Questions?

Harmonics?!

to be continued…