Frequently Asked Questions by Low-Tension (L.T.) Consumers

&

Frequently Answered Questions by the Solutions Providers, **TAS PowerTek, Nashik-422 010, India.**

Power Factor and Power Factor Controllers:

1] What is Power Factor?

Power Factor (P.F.) is an indicator of efficient utilization of AC Electrical Power.

In an AC (Alternating Current) electrical power system, P.F. is defined as the ratio of **real** power flowing to the load, to the **apparent** power in the circuit and is a dimensionless number, because it is just a ratio of two numbers.

In order to have an “efficient” system, we want P.F. to be as close to 1.0 (i.e. 100%) as possible, this will provide maximize utilization of the electrical circuit.

Simpler Definition of P. F.: The **displacement power factor** is the **power factor** due to the phase shift between voltage and current at the fundamental line frequency. It can be defined as the cosine of the angle between the current and the voltage.

The conventional measurement of the power factor is relevant only for loads that are linear and the waveforms are purely sinusoidal.

With the increase in non-linear loads such as inverters, drives, etc this definition of the power factor is not adequate. This is because the harmonics have an impact on the power factor.

Thus, the total harmonic distortion should also be considered while calculating power factor.

2] How is True Power Factor different from Measured Power Factor?

The true power factor refers to the measured power factor at the system frequency which is adjusted for the Harmonic distortion.

Distortion Power Factor = $1 / \sqrt{(1+\mathrm{THD}^2)}$

Where, THD refers to the Total Harmonic Distortion.

True Power Factor = Displacement Power Factor x Distortion Power Factor.

Thus for loads which have high harmonic content, the True Power factor needs to be calculated.

3] Power Factor related Terminologies and Basic (Simple!) Mathematics:

* An inductive load requires a magnetic field to operate and in creating such a magnetic field causes the current to be out of phase with the voltage (the current lags the voltage).

* Power Factor correction is the process of compensating for the lagging current by creating a leading current by connecting capacitors to the supply.

P.F (Cos Ǿ) = kW / kVA or P.F (Cos Ǿ) = True Power / Apparent Power.

kW is Working Power (also called Actual Power or Active Power or Real Power).

kW is the power that actually powers the equipment and performs useful work.

kVAr is Reactive Power.

kVAr is the power that magnetic equipment (transformer, motor and relay) needs to produce the magnetizing flux.

kVA is Apparent (Total) Power.

kVA is the “vectorial summation” of kVAr and kW.

The vectorial summation uses the trigonometric formulae applicable to a Right-Angled Triangle where the kW is the Base of the triangle, the kVAr is the height of the triangle and the resultant kVA is the hypotenuse.

4] What causes Low Power Factor?

Inductive loads, which are sources of **Reactive** Power, are mainly responsible for low P.F.

These constitute a major portion of power consumed in industrial complexes and include, but not limited to:

* Induction Motors

* High Intensity Discharge Lighting etc.

* Fluorescent Lamps (CFLs, Tube Lights), LED Bulbs

* Computer Power Supplied based on Switch-Mode Technique.

* Inductive Loads of Transformers, Solenoids, and Contactor Coils.

* Non-Linear loads (like UPS, Soft Starter, and Variable Frequency Drive (VFD) etc.)

The best way to improve a poor Power Factor caused by non-linear loads is to remove the harmonic currents.

5] Disadvantages / Problems due to Low Power Factor?

* Poor power efficiency,

* Increasing the apparent power drawn from the distribution network.

* Overloading of Transformer,

* Overloading of Bus Bars,

* Overloading of Switch Gears,

* Overloading of Cables and other Distribution Devices

6] Why improve Power Factor?

* Increased capacity and reduced losses in electrical system: Low Power Factor causes losses in distribution system. By improving P.F., losses can be reduced which in turn can enhance the capacity to bear additional load in your system.

* Improves voltage profile and reliability of installations

* Moreover, low P.F. not only causes unnecessary increase in generation and transmission capacity of the utility, in a broader perspective, it actually increases amount of greenhouse gases that get released into the atmosphere.

* L.T. Commercial consumer having contract demand of 10 kVA and above, L.T. Industrial consumers, L.T. Public Water Works may be required to pay Power Factor surcharge as may be specified by the respective State Level Electricity Regulatory Commission.

In summary, improved P. F. achieves:

- **Reduction in Maximum Demand (kVA)**
- **Reduction in Energy (kWH) consumption**
- **Longer life of the existing electrical distribution components like Motors, Transformers, Switch- Gears, Cables, etc.**
- **Optimize the connected load for improved plant load factor.**
- **Avoid high current consumption losses.**
- **Decrease Maximum Demand kVA, thus avoiding penalty and Demand Charges.**

7] How to improve Power Factor?

* Install Power Capacitors of appropriate Voltage rating and Micro-Farad Value, close to motors / loads

* Switch on or off the capacitor in tandem with motor / load – This will maximize reactive compensation and provide relief to your internal electrical network. To avoid manual operation, you may install Automatic Power Factor Controller (APFC).

* Use Automatic Power Factor Controllers that will regulate Power Factor close to Unity (1.000).

Depending on load, the Automatic Power Factor Controller will switch the Capacitor Bank(s) On or Off.

8] What is the range of the Power Factor Values, the typical values, and the desired values?

The Power Factor value is between 0.00 and 1.00.

A value of P.F. = 0.00 means, it is a Purely (Ideal) Reactive Power Load and there is No (Zero) Active Power Load. It also means, Apparent Power is equal to Reactive Power.

A value of P.F. = 1.00 means, it is a Purely (Ideal) Active Power Load and there is No (Zero) Reactive Power Load. It also means, Apparent Power is equal to Active Power.

In real-life, there is neither Ideal Re-active Power Loads nor Ideal Active Power Loads!

The Ideal P.F. Values of 0.00 and 1.000 are without any Sign. The “Sign” Convention to indicate the nature of the P.F. as resultant, net-balance, “Inductive” or “Capacitive” is generally as:

+Ve P.F. Value indicating the resultant balance Load Reactive Power being Inductive

-Ve P.F. Value indicating the resultant balance Load Reactive Power being Capacitive.

If the System Power Factor is above 0.8, the System / Device are using power efficiently.

A standard AC Power Supply with Inductive Load has a Power Factor in the range of 0.70 to 0.75

An AC Power Supply with a good P.F. Controller has a typical Power Factor in the range of 0.950 to 0.990

An IDEAL 1.000 value of P.F. is rarely set as a Target P. F. for the Switched Capacitor Banks P. F. Correction Controllers because it may result in the effective net balance Reactive Power to be slightly “Capacitive”, which is to be avoided.

9] How Power Capacitors help in P. F. Improvements?

Considering Ideal Inductive Reactive Load and Ideal Capacitive Reactive Load, and also considering the Voltage waveform as a reference, the current in a purely Inductive Circuit lags Voltage by 90 electrical degrees. Similarly, again considering the Voltage waveform as a reference, the current in a purely Capacitive Circuit leads by 90 electrical degrees. Note, one complete AC Sinusoidal Cycle has 360 electrical degrees.

Therefore, the Inductive Current and Capacitive Current are opposite in phase to each other with the Phase Angle difference of 180 electrical degrees.

This perfect opposition helps in cancelling these two components mutually such that if these are equal in magnitude, then, the resultant balance reactive component is zero (nil).

If the magnitudes are not the same, then, the smaller magnitude component gets subtracted from the larger magnitude component and the net balance component has the same reactive nature as that of the larger magnitude component.

As the present Electrical Loads have the Inductive Reactive Component, the opposite corrective Reactive Component is provided by the Capacitors as Capacitive Reactive Component.

However, in actual practice, rather than totally eliminating all the Inductive Reactive Component, a small amount of Inductive Reactive Component as net balance is acceptable. That is the significance of setting the Target P. F. value as say 0.999 Inductive and not exactly 1.000

Induction motors, transformers and many other electrical loads require magnetizing current (kVAr) as well as actual power (kW).

By representing these components of apparent power (kVA) as the sides of a right-angled triangle, we can determine the apparent power from the right triangle rule: $kVA^2 = (kW^2 + kVAr^2)$.

To reduce the kVA required for any given load, you must shorten the vertical-line that represents the kVAr.

This is precisely the role of the Power Factor Improvement Power Capacitors.

By supplying kVAr right at the load, the Power Capacitors relieve the Utility of the burden of carrying the extra kVAr. This makes the utility transmission / distribution system more efficient, reducing cost for the utility and their customers.

10] How to determine the required Total Reactive Capacitive kVAr Value to improve Power Factor?

For Example:

Existing Load in kW = 48 kW (Active Power). This remains the same before and after the P. F. improvements.

Existing Power Factor = 0.84 (Before Improvement)

Existing Load In kVA = (Existing Load in kW / Existing Power Factor) = 48.0 / 0.8 = 57 kVA

Target Power Factor, better than the existing, towards the ideal value of 1.000, as P.F. = 0.97

Revised Load in kVA (Existing Load in kW / Target Power Factor = 48.0 / 0.97= 49.48 kVA

Desired rating of the Capacitor Bank to improve the Power Factor from the present 0.80 to the target 0.97

$\sqrt{}$ (Existing kVA^2 – Load in kW^2) – $\sqrt{}$ (Revised kVA^2 – Load in kW^2)

√ ([57*57] – [48*48]) - √ ([49.48*49.48] – [48*48])

√ ([3249] – [2304]) - √ ([2448.2704] – [2304])

√ (945.00) - √ (144.2704)

{30.7408 – 12.0112}

= 18.7296 Say: A round-figure value of: 19.0 kVAr.

APFC design may be in 3 stages using Individual Capacitor Banks, 1 each of: 2 kVAr; 3 kVAr; 6 kVAr; 8 kVAr

11] Alternative method to determine the required Total Reactive Capacitive kVAr Value to improve Power Factor to a better target value, based on a Multiplying Factor from the Table:

For Example:

Calculation of required capacitor:

* Suppose Actual P.F. is 0.80, the required (target) P.F is 0.98, and Total Load is 516 kVA.

* **Power Factor = kW / kVA**

kW = kVA x Power Factor

= (516 x 0.80) = 412.8

Required Capacitor = kW x Multiplying Factor (available from the Table).

= (516 x 0.80) x Multiplying Factor

= 412.8 x 0.547 (See Table to find Value according to P.F 0.80 to P.F of 0.98)

= 225.80 kVAr

Multiplying factor for calculating kVAr

Target PF

	<- Desired Power Factor ->																
	0.1	0.80	0.82	0.84	0.86	0.88	0.90	0.91	0.92	0.93	0.94	0.95	0.96	0.97	0.98	0.99	1.0
Existing Power Factor	0.70	0.270	0.322	0.374	0.427	0.480	0.536	0.564	0.594	0.625	0.657	0.691	0.728	0.769	0.817	0.877	1.020
	0.71	0.242	0.294	0.346	0.399	0.452	0.508	0.536	0.565	0.597	0.629	0.663	0700	0741	0789	0.849	0.992
	0.72	0.214	0.266	0.318	0.371	0.424	0.480	0.508	0.538	0.569	0.601	0.635	0.672	0.713	0.761	0821	0.964
	0.73	0.186	0.238	0.290	0.343	0.385	0.452	0.480	0.510	0.541	0.573	0.607	0.644	0.685	0733	0.793	0.936
	0.74	0.159	0.211	0.263	0.316	0.389	0.425	0.453	0.483	0.514	0.546	0.580	0617	0.658	0.706	0.766	0.909
	0.75	0.132	0.184	0.236	0.289	0.342	0.398	0.426	0.455	0.487	0.519	0.553	0.590	0.631	0.679	0739	0882
	0.76	0.105	0.157	0.209	0.262	0.315	0.371	0.399	0.429	0.480	0.492	0.526	0.563	0.604	0.65	0.712	0.855
	0.77	0.079	0.131	0.183	0.236	0.296	0.345	0.373	0.409	0.434	0.466	0.500	0.537	0.578	0.626	0.686	0.829
	0.78	0.052	0.104	0.156	0.209	0.262	0.318	0.348	0.376	0.407	0.439	0.473	0.510	0.551	0.599	0.659	0.802
	0.79	0.026	0.078	0.130	0.183	0.235	0.292	0.320	0.350	0.381	0.413	0.447	0.484	0.525	0.573	0.633	0.776
	0.80		0.026	0.104	0.157	0.210	0.265	0.294	0.324	0.355	0.387	0.421	0.458	0.499	0.547	0.609	0.750
	0.81			0.078	0.131	0.184	0.240	0.268	0.298	0.329	0.361	0.396	0.432	0.473	0521	0.581	0.724
	0.82			0.052	0.10	0.158	0.215	0.242	0.272	0.303	0.355	0.369	0.406	0.447	0.495	0.555	0.698
	0.83			0.026	0.079	0.132	0.188	0.218	0.248	0.277	0.309	0.343	0.380	0.421	0.469	0.529	0.672
	0.84				0.053	0.10	0.162	0.190	0.220	0.251	0.283	0.317	0.354	0.395	0.443	0.503	0.646
	0.85				0.027	0.080	0.136	0.164	0.194	0.256	0.257	0.291	0.328	0.369	0.417	0.477	0.620
	0.86					0.063	0.091	0.137	0.167	0.198	0.230	0.264	0.301	0342	0.390	0.450	0.593
	0.87					0.027	0.083	0.111	0.141	0.172	0.204	0.238	0.275	0316	0.364	0.424	0.567
	0.88						0.058	0.084	0.114	0.145	0.177	0.211	0.248	0.289	0.337	0.397	0.540
	0.89						0.028	0.055	0.085	0.117	0.149	0.183	0.220	0.261	0.309	0.369	0.512
	0.90							0.028	0.058	0.089	0.121	0.15	0.192	0.233	0281	0341	0.484
	0.91								0.027	0.068	0.080	0.124	0.161	0.203	0.250	0.310	0.453
	0.92									0.031	0.063	0.097	0.134	0.176	0.223	0.283	0.426
	0.93										0.032	0.066	0.103	0.145	0.192	0252	0.395
	0.94											0.034	0.071	0.113	0.160	0.220	0.363
	0.95												0.037	0.079	0.126	0.186	0.329
	096													0.042	0.089	0.149	0.292
	0.97														0.047	0.107	0.250
	0.98															0.060	0.203
	0.99																0.143

12] Automatic Power Factor Correction (APFC Controllers):

Power Factor Improving:

* Please check if required kVAr of Power Capacitors are installed.

* Check the type of Capacitor installed is suitable for application or the capacitors are de-rated.

* Check if the capacitors are permanently 'ON'. The Capacitors are not switched off

* When the load is not working, under such condition, the average Power Factor is found to be on a lower side.

* Check whether all the capacitors are operated in APFC, depending up-on the load operation.

* Check whether the APFC installed in the installation is working or not. Check the CT connection is taken from the main incomer side of transformer, after the fixed compensation of transformer.

* Check if the load demand in the system is increased.

* Check if power transformer compensation is provided.

Thumb Rule, if Load Horse Power (H.P.) is known.

* The compensation for motor should be calculated taking the details from the rating plate of motor or

* The capacitor should be rated for 1/3 of Load H.P.

kVAr Required For Transformer Compensation:

Transformer		**Required kVA**
<= 315 kVA T. C.	=	5% of kVA
315 kVA to 1000 kVA	=	6% of kVA
>= 1000 kVA	=	8% of kVA

13] Where to connect the Power Capacitor(s)?

Fix compensation should be provided to take care of Power Transformer.

Power and Distribution transformers, which work on the principle of electro-magnetic induction, consume reactive power for their own needs even when its secondary is not connected to any load.

The Power Factor will be very low under such situation. To improve the Power Factor, it is required to connect a fixed capacitor or Capacitor Bank at the L.T. side of the Transformer, of approximate kVAr of Power Capacitors required.

If the installation is having various small loads with the mixture of large loads then the APFC should be recommended. Note that APFC should have minimum step rating of 10% as smaller step.

If loads are small, then the capacitor should be connected parallel to load. The connection should be such that whenever the loads are switched-on the capacitor also switches-on along with the load, or as per the Intelligent Switching algorithm.

Note that APFC panel can maintain the Power Factor on L.T side of transformer and it is necessary to provide fix compensation for Power Transformer.

In case there is no transformer in the installation, then the C.T. for sensing Power Factor should be provided at the incoming of main switch of the plant.

14] How to test the Capacitor Bank at the Site?

Voltage Measurements:

a] Check the voltage using a good multi-meter at power capacitor terminals.

b] Please note that the Power Capacitor Current of 440 Volt (Line-to-Line) rated capacitor connected to a system of 415 Volt (Line-to-Line) will be lesser than rated value.

It is not difficult to calculate the resultant kVAr of the power capacitor due to variation in supply voltage.

The kVAr of capacitor will not be same if voltage applied to the capacitor and frequency changes.

The example below shows how to calculate capacitor current from the measured value at site.

Example:

1. Name plate details – 15 kVAr, 3 phases, 440 Volts (Line-to-Line), and 50 Hz Capacitor.

Measured Voltage – 425 Volts (L-to-L), measured frequency – 48.5 Hz

kVAr = (fM / fR) x $(VM / VR)^2$ x kVAr

Corrected Effective kVAr = (48.5/50) x $(425 / 440)^2$ x 15

= 13.57 kVAr.

2. Name plate details – 15 kVAr, 3 phases, 415 Volts (Line-to-Line), and 50 Hz Capacitor.

Measured voltage – 425 Volts (L-to-L), measured frequency – 48.5 Hz

kVAr = (fM / fR) x $(VM / VR)^2$ x kVAr

kVAr = (48.5/50) x $(425 / 415)^2$ x 15

= 15.26 kVAr

Capacitor Current Measurements:

The capacitor current can be measured using a Multi-meter or a Tong-Tester or an Ammeter.

Make a record of measurement data of individual phase and other parameter.

Check whether the current measured is within the limit value with respect to supply voltage & data given in the name plate of capacitor. Refer formula for calculation.

Formula for calculating rated current of capacitor with rated supply voltage and frequency.

l = kVAr x 10^3 / (√3 x V) L-to-L

Example:

15 kVAr, 3 phases, 440 V, 50 Hz Capacitor.

l = kVAr x 10^3 / (√3 x V) L-to-L

l = (15 x 1000) / (1.732 x 440) L-to-L

l = 19.68 Amps Line

15 kVAr, 3 phases, 415 V, 50 Hz Capacitor

l = kVAr x 10^3/ (√3 x V) L-to-L

l = (15 x 1000) / (1.732 x 415) L-to-L

l = 20.87 Amps Line.

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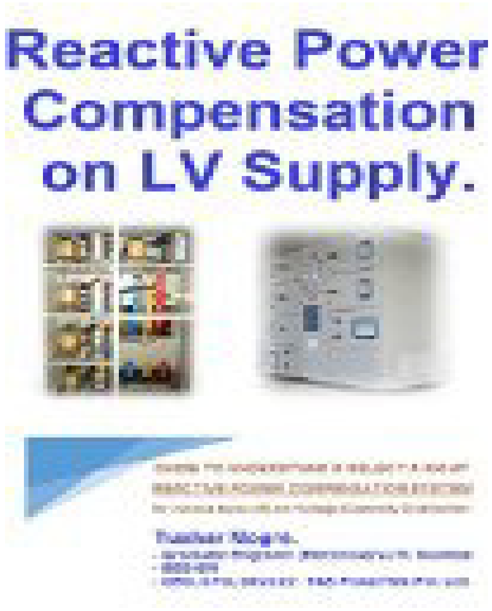
Book Title: **Reactive Power Compensation on LV Supply: Guide to Understand / Selection of a right reactive power compensation system.**
Author: Mr. Tushar P. Mogre, CEO, Director, TAS PowerTek Pvt. Ltd.
e-Book Published by: Amazon.com

Web-link: http://www.amazon.com/gp/aw/d/B00o7YLLYY



Book Details:

- **Format:** Kindle Edition
- **File Size:** 2687 KB
- **Print Length:** 221 pages
- **Publisher:** Tushar Mogre. - CEO, Director, TAS PowerTek Pvt. Ltd. (5 October 2014)
- **Sold by:** Amazon Digital South Asia Services, Inc.
- **Language:** English
- **ASIN:** B00O7YLLYY
- **Text-to-Speech:** Enabled
- **X-Ray:** Not Enabled
- **Word Wise:** Not Enabled
- **Enhanced Typesetting:** Not Enabled

Book Description:

We are living in the era of Electricity Supply System supplied to us as AC – Alternating Current. This system is now the universal standard. Obviously, it is adapted because of many good features over the DC supply system. But with AC supply system, the “POWER FACTOR” is one term that is really important.

Electrical supply system efficiency and level of utilization of Electricity distribution equipment are improved with Power Factor near unity. With improvement in Power Factor, there is current reduction for the same value of Watt power consumption.

The Power Factor on an electrical supply system with advent of new technology products that creates non-linear electrical loading and generates various challenging aspects for designing of Reactive Power Compensation Systems (PF correction Systems). Some major issues that are:

•New version of Power Electronics Based equipment normally generate Electrical harmonics. This has created some challenges for designing of PF correction Systems.

•Even the loading pattern in multiple cases is seen to be changing abruptly, causing abrupt changes in Power Factor.

•Sometimes, the loading patterns in three different phases of the supply systems are different.

In such case, the Power Factor at any given moment may be different in three phases.
All these effects seen are either individually or sometimes in combinations. These can be in variable degrees of severity.

The systems therefore are to be designed based upon the consumer loading. The consumer loading based upon issues like PQ (Power Quality), Speed of load changes, difference in loading between the phases, environmental conditions, the safety norms etc.

In every category of electrical consumer like Industrial, Commercial, Domestic, Agricultural, Small cottage businesses would face challenge of designing different type of Power Factor correction system. Even the sub-categories within these primary categories would face challenge to design such new system.

In fact the best approach is to design the system based upon the every individual consumer’s loading pattern survey results. And based on the finding in such survey results, the rightly configured “Power Factor Correction System” should be designed.

Thus, this book tries to bring out the various options in present day commercially available technology (Year 2014) and how to utilize it best for the specific consumer needs.

For providing the Power Factor Compensation, one has to know how much compensation to be provided. For knowing that one has to know what are the electrical parameters that are to be measured.

Thus, this book starts with initially some basics of Electrical Engineering which is studied by Engineers. Therefore, some may find first two or three chapters as the elementary level. Still it is given in the book because many of us Engineers who have passed years back would be able to brush up the fundamentals of electrical engineering.

Further chapters would discuss the present day technology and the right approach towards designing the right “Reactive Power Compensation System”.

In this book, the approach is of practicality on the subject rather than a theory. Still, one has to take help of theory to reach the right practical approach. Thus, naturally some theory is always touched upon. The approach of the book is not to get into Mathematical Derivations of the theorems.

But to understand the Basics of the already established theorems and practically apply these to design the right system.

In this book, the approach is even to explain the situation diagrammatically. Therefore reader may find multiple diagrams (referred as Fig.--.-) which may be useful in visualization.

Hope, reader finds this book informative and useful as handbook for designing the LV application Reactive Power Compensation Systems.

Thank you.

(**Tushar P. Mogre**)

Document Revision Dated: 29th April 2017.

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