The Journal of CPRI,
Vol. 10, No. 4, December 2014 pp. 765-768

Concept of APFC with reference to the energy efficiency

Vishal Singhal*

Abstract- Increasingly, Indian Industry is paying one of the highest power tariffs in the world. Countries in this club such as Germany and Italy have benefited from Automatic Power Factor control as a competitive edge. They are already global leaders in Automatic Power Factor Compensation (APFC) Capacitors and Panels. This paper is aimed at APFC users and takes a hands-on look at extending the lifetime payback of APFC equipment. The effects of Current, Voltage, Harmonics and Temperature and their interplay are discussed. These produce degradations in Capacitors and Contactors. Subtle problems go unnoticed since the equipment is operating silently in a corner, until a catastrophic breakdown occurs. This paper also discusses practical guidelines for panel designers and users. Peak Inrush Current limiting, forced cooling, Component specifications, component selection and the role of the APFC controller with its protective functions are examined.

Keywords: *Closed loop controller, DC-DC converter, maximum power point tracking, solar photovoltaic.*

1.0 INTRODUCTION

The demand for energy is projected to grow twice as fast in Asia as for the rest of the world over the next 20 years. India is projected to claim a significant portion of this Asian demand. However, with a smaller reserve of resources, Electricity prices in Asian countries are already some of the highest in the world. The per-unit cost in India is almost twice that in Canada.

With increasing global competition, countries with higher electricity costs can benefit significantly from improvements in Energy Efficiency [1-3]. Further, improvements in energy efficiency are already proven to have the fastest payback,Power Factor (PF) improvement is therefore one of the fastest ways to a better bottom-line. Compared to improving availability through Generation.

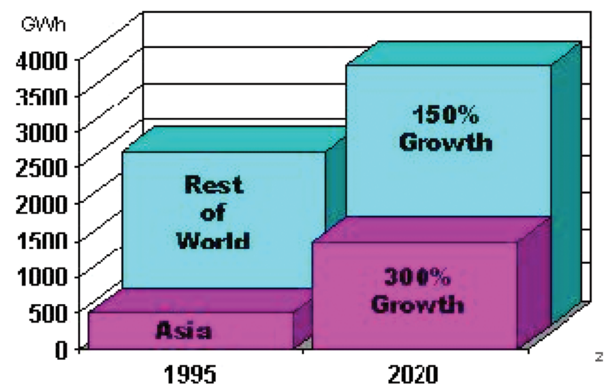

FIG. 1 EXPECTED GROWTH OF ELECTRIC ENERGY DEMAND

2.0 THE PRINCIPLE OF PF COMPENSATION

While the ideal Power Factor (PF) is Unity or 1, most Industrial loads have a PF lower than

*Technical Support Manager, Mahindra Heavy Engines (P) Ltd., Chakan, Taluka-Khed. District, Pune - 410501, India.
E-mail: Singhal.vishal@mahindra.com

1. Moreover, this lower PF is usually Inductive, arising out of the windings of Transformers, Motors, and the like. These loads consume kVARs (the Watt less component) from the supply line.

The principle of PF Compensation is to supply these kVARs via a capacitor located close to the load, reducing the current drawn from the supply line.

3.0 AUTOMATIC PF COMPENSATION

For an Industry with dynamically changing loads, Automatic PF Compensation affords the best Return on Investment, since the kVAR investment required is smaller than with fixed capacitors needed to meet the entire load.

Automatic PF Correction also avoids Leading PF situations by switching off extra capacitors.

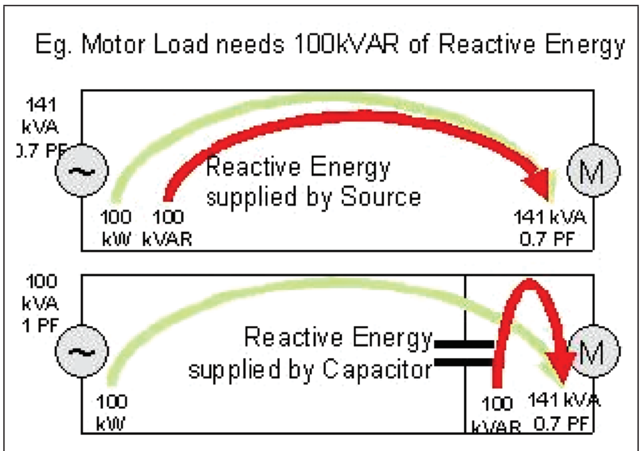

FIG. 2 PRINCIPLE OF PF COMPENSATION

4.0 CAPACITOR CONSTRUCTION, FACTORS AFFECTING LIFE-TIME COST

The PF Capacitor can be visualised as a pair of conductive surfaces (the plates) separated by an insulating dielectric. One layer of this sandwich is barely 10 to 20 micron thick.

4.1 The Dielectric

Older capacitors were made with a paper dielectric immersed in a heavy mineral oil called PCB (poly-chlorinated-bi-phenyl). These were bulky and ran very hot even though the oil aided heat dissipation [6-8]. But they were robust, since the high Tan Delta (resistive) loss of the PCB oil dielectric provided built-in inrush protection. Also, PCB is so stable that it never degraded, even in discarded capacitors in waste dumps, contaminating ground water and the environment. Unfortunately, PCB is carcinogenic. Finally, it was banned.

Today, the dielectric is usually a 6 micron-thick PP (polypropylene) plastic film, free from impurities or pin holes. PP has excellent physical (non-tearing) and electrical (very low loss) properties for a dielectric. Especially its self-healing property, which is explained shortly [4-5]. Unfortunately, the low loss allows high inrush current. To make things worse, fuses for the capacitors are either excessively sized or are missing altogether. In addition, PP a petroleum derivative is extremely flammable. An inadequately designed APFC panel causes capacitor overheating, which is as dangerous as smoking over a drum of petrol.

Some better capacitors have a combination paper-film dielectric 15 micron thick. This can result in a higher purchase cost, but a lower lifetime cost since it is far more reliable and requires fewer replacements.

4.2 The Conductive Surface

The conductor surface may be merely a thin metal spray on the plastic dielectric film. This gives a low-cost but weak construction. Capacitors that are more reliable may use aluminum foil, or thicker vapor-deposited aluminum, on both sides of the dielectric film [9].

Thicker dielectrics and foils are more reliable (better inrush current and voltage surge withstanding), but also require more surface area for a given capacitance. This means more material, larger capacitor cans and slightly larger panels.

4.3 75% of the APFC Investment

In The Capacitor is placed in series with a switch, a heavy-duty relay, called a Contactor. These two components comprise 75% of the cost of an APFC panel. The contactor must be rated for Capacitor switching duty, specified for inrush current typically 100 In.

The APFC Panel designer and user must therefore consider a judicious specification, since the lowest bid does not usually give the lowest lifetime cost.

5.0 APFC PANEL DESIGN CONSIDERATIONS: CRITICAL FACTORS

A The APFC Panel designer attempts to simultaneously minimise:

- Field trouble and
- Cost

In other words, how to achieve a given lifetime cost (which the Manufacturer would like to minimise) whilst meeting the specifications (which the User would like to maximise) and the attendant field conditions [10-14].

Most Application related problems arise from:

- Improper Design or Component Sizing, or
- Improper Installation, Settings or Use This results in:
- Damage or Reduced ability to Compensate
- Higher Maintenance
- PF and kVA Demand Penalties to the User. The latter is because poorer PF immediately raises the kVA consumed by a given reactive load.

The key operating conditions to be considered are the peaks of

- Current. Especially due to Inrush and Harmonic Current and
- Voltage
- Temperature.

These determine the life of Capacitors and Contactors, which comprise almost 75% of the cost of an APFC Panel [15-17].

Unfortunately, these conditions are not often precisely known at the time of designing the

Panel. Nor would they stay constant thereafter, since newer (e.g. non-linear) loads

may be added at site from time to time. Later, this paper shows how the APF Controller provides some protection from these detrimental effects.

6.0 CONCLUSION

The cost breakup of a typical APFC Panel for LT 415v application, is:

- Capacitors 50%
- Contactors 25%
- Cabinet 15%
- Cabling, Safety Parts 5%
- Controller 5%

Contracting adds a 20% overhead. These are only typical figures, and may vary.

The astute reader would notice:

- The Controller is the Brain of the system
- The Controller must provide the intelligence to protect the equipment. I.e., brain rather than brawn. Safety alarms and tripping, a critical necessity, is enabled by the fact that it is the Average PF for the month that needs to be maintained. Instantaneous PF need not be maintained during abnormalities.
- This is the ONLY way to minimize the cost of the complete panel. Without well-designed protection facilities in the Controller the alternative, of over-sizing or over-rating the components to meet the exigencies at site, is far more costly.

REFERENCES

[1] Liu yaoping, Smedley K M, “Control of a Dual Boost Power Factor Correction for High Power Applications,” Annual Conference of the IEEE Industrial Electronics Society (IECON'03), pp. 2929-2932, 2003.

[2] Chongming Qiao Keyue M Smedley,“A General Three-phase PFC Controller for Rectifiers With a Parallel-Connected Dual-Boost Topology,” IEEE Transactions on Power electronics, vol. 17, no.6, pp. 925-934, 2002.

[3] Jovanovic, M M , Jang, Y“State-of-the-art, single-phase, active power-factor-correction techniques for high-power applications - an overview,” IEEE Transactions on Industrial Electronics, vol. 52, pp. 701-708, 2005.

[4] Chen Zhe,“Boost APFC device design,” Electrical Technology, vol.1, pp. 45-50, 2010.

[5] W Zhang, G Feng, Y Liu, et “A digital power factor correction (PFC) cont optimized for DSP,” IEEE Transactions on Power Electronics, vol. 19, no. 6, pp. 1474-1485, 2004.

[6] J Toth III and D. J. Velazquez "Benefits of an automated on-line harmonic measurement system", IEEE Trans. Ind. Appl., vol. IA-22, no. 5, pp.952 -963 1986.

[7] A Guide to Power Factor Correction for the Plant Engineer, Sprague Electric Company Publisher, 1962.

[8] J Sun, "On the Zero-Crossing Distortion Single-Phase PFC Converters," IEEE Trans. Power Electronics, vol.19, pp. 685 - 692, May 2004.

[9] Muhammad Mansoor Khan, "A Modified Boost Topology to Minimize Distortion in PFC Rectifier," IPEMC 2004, vol. 3, pp. 1248 - 1252, Aug. 2004.

[10] J C Crebier , B Revol and J P Ferrieux "Boost-chopper-derived PFC rectifiers: Interest and reality", IEEE Trans. Ind. Electron., vol. 52, no. 1, pp.36 -45 2005.

[11] M T Zhang , Y Jiang , F C Lee and M M Jovanovic "Single-phase three-level boost power factor correction converter", IEEE App. Power Electron. Conf., pp.434 -439, 1995.

[12] J C Wu, H L Jou, K D Wu and N C Shen, "Power converter-based method for protecting three-phase power capacitor from harmonic destruction", IEEE Trans. Power Delivery, vol. 19, pp. 1434-1441, Jul. 2004.

[13] D M Vilathgamuwa and H M Wijekoon, S S Choi, "Investigation of resonance phenomena in a DVR protecting a load with PF correction capacitor", The Fifth International Conference on Power Electronics and Drive Systems, pp, 811-815, 2003.

[14] D Detjen, J Jacobs, R W De Doncker, H O Mall, "A new hybrid filter to dampen resonances and compensate harmonic currents in industrial power systems with power factor correction equipment", IEEE Trans. Power Electron., vol. 16, pp. 821-827, Nov. 2001.

[15] H Akagi, "Instantaneous reactive power compensators comprising switching devices without energy storage components", IEEE Trans. Ind. Applicat., vol. IA-20, 1984.

[16] F Z Peng, G W Ott, and D J Adams, "Harmonic and reactive power compensation based on generalized instantaneous reactive power theory for three-phase four-wire systems", IEEE Trans. Power Electron., vol. 13, pp.1174 -1181, 1998.

[17] J Jacobs, D Detjen, and R W De Doncker, "Rapid prototyping tools for powerelectronic systems Demonstration with shunt active power filters", Proc. IEEE Int. Conf. Ind. Electron., Contr. Instrum., 2000.