# ART OF SMART CONTROL OF REACTIVE POWER / POWER FACTOR – CASE STUDIES

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## ABSTRACT

Reactive power and power factor are important parameters in the tariff. To improve the efficiency of the system, utilities started imposing the penalty on poor power factor, further it introduced TOD tariff and also offered incentives to motivate the consumers to maintain better power factor. To avoid the penalty as well as to get the maximum incentives, consumers started using more and more capacitors with or without switching techniques. In many Indian utilities 'billed power factor' is calculated on the basis of monthly consumption of parameters such as kWH, kVAH etc. These monthly measured parameters are based on import and export of reactive power and majority of the existing consumers are unaware of this method. With lack of knowledge of the engineering of measurement in billing meters, consumers are taking corrective actions at load end and many a time to meet the 'average' power factor benefit they overcompensate the system.

In this paper, few case studies have been presented. To get more insight into the issue, the actual measurements were taken at LT as well as HT consumers. In a few cases, it was observed that after removing overcompensation by fixed capacitors, the total bill amount was reduced up to 48%. In few premises it was observed that due to overcompensation, billed KVA and/or KVAH was increased during the night even when no active load was present and average power factor was as low as 0.2 whereas it was reflected as unity billed power factor. In another case, it was found that billed power factor was 0.98 but the same consumer was achieving this billed power factor by the export of 200 kVAR reactive power consistently. From all these observations it is essential to shift the focus from 'Power Factor' management to 'Reactive Power' management strategy. The utility needs to have transparent billing system and should educate the consumers time to time on the changes. The consumers should install Smart Energy Management system and monitor important electrical parameters.

## 1 INTRODUCTION

Reactive power is required to build up the magnetic field in motors, discharge lamps, transformers, generators with lagging power factor, as well as in the cables and overhead lines with high current loading. It is said that reactive power is "wattless" power, as it is not converted into heat, light or torque, but oscillates back and forth between source and load [1]. However, the utility has to spend on this power and still, they are not getting paid for it. The flow of reactive power from the utility causes blockage of utility capacity, energy losses as well as it results into additional voltage drops [2]. Reactive power compensation is important not only in transmission and distribution systems, where it is required to improve the voltage and increase the transmission capacity but also it is important at load side to maintain the voltage and to reduce the kVA demand (which is one of the billing parameters).

Power factor needs separate discussion as with the introduction of non-linear loads, one needs to specify whether displacement power factor – when the only fundamental frequency is present or true power factor - when harmonics are present is being considered.

"The displacement power factor cos ϕ1 is defined as the quotient of active power and apparent power with fundamental frequency" (in the case of sinusoidal voltage and non-sinusoidal current) as given in equation 1 [1]:

$$\boldsymbol{Cos\emptyset 1} = \frac{P_1}{\sqrt{P_1^2+Q_1^2}} = \frac{P_1}{S_1} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(1)$$

"The power factor (true) λ is defined as the quotient of active power and apparent power (in this case fundamental as well harmonic frequency" components are considered) as given in equation 1 [1]:

$$\lambda = \frac{|P|}{\sqrt{P^2+Q_1^2+Q_d^2}} \quad \ldots\ldots(2)$$

The active power $P_1$ and the reactive power $Q_1$ are related to the fundamental frequency of current and voltage, and the distortion power $Q_d$ is related to the harmonic currents and the fundamental frequency of the voltage.

## 2 Billing system considerations

Normally a utility charges the customers based on two-part tariff i.e. kVA Demand and monthly kWh consumption. In India, almost all utilities have imposed a limit of power factor (p.f.) as 0.9 [4] and it is calculated as kWh/kVAh on monthly basis (average p.f.). Utility levy penalties on the p.f. below 0.9 and offer incentives if the customer maintains p.f. above 0.95 [4]. This type of p.f. based penalty and incentive structure were introduced around the year 2000. It revolutionized the tariff structure with the introduction of TOD tariff. To get the benefit of maximum possible incentives from electricity boards, many consumers blindly installed capacitors (mostly fixed type). With the limitations in the specification of the billing meter - ignoring leading kVAR [3], consumers started installing more and more capacitors irrespective of the load requirement. Hence, during light load/no-load conditions reactive power was exported from the consumer to the utility grid. Recently, after the realization of the effects of reactive power export such as overvoltage, blockage of capacity, MSEDCL changed the method of calculation of billing power factor and started considering import and export of reactive power from September 2018 [4]. All of sudden, many consumers enjoying incentives for the years together lost the incentive and in some cases started getting penalties due to high export of reactive power. The authors surveyed many HT and LT consumers in and around Pune and in almost 90% cases it was found that the consumers were using fixed capacitors and the same were ON during low load/no load condition. Class A, NABL calibrated Power Quality analyser was used for the study/measurement in all the cases.

Few of the case studies are presented here.

## 2 CASE STUDIES

In Maharashtra state, MSEDCL has started considering export of reactive power from the consumer for calculations of billed power factor with effect from September 2018 billing cycle. Out of many enquiries, the authors specifically selected few case studies to discuss in this paper. Individual cases are reflecting rKVAh export reduction after partial immediate corrections. The same is summarized in the tables in each case studies.

### Low Tension Customers:

Case study No. LT - 1

Consumer details:

1. Type of industry: Auto ancillary
2. Contract demand: 100 kVA
3. Highest kVA MD in last 12 months: 47 kVA
4. Connected kVArs: 70 kVAr (in Fixed mode)

The results are as below.

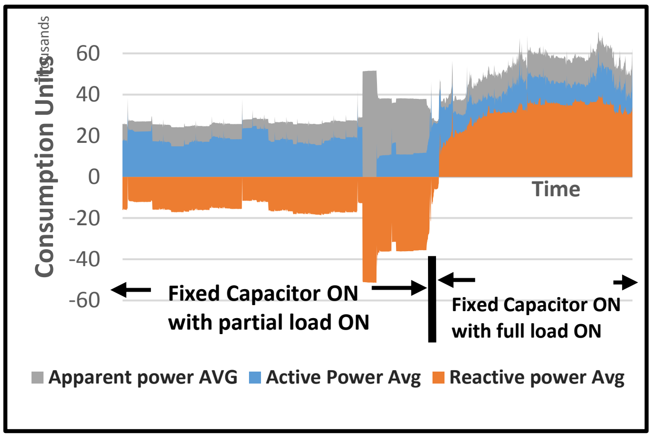


Fig-1: Variation of Active, Reactive & Apparent Power (with Fixed Capacitors) - Auto ancillary

From the above graph it can be seen that during partial load due to excess capacitors (over compensation) in circuit, reactive power is being exported. This not only resulted in to the loss of power factor incentive of consumer but it is clear that the kVAh also shoots up. It is also evident that during full load condition, reactive power is being imported (under compensation) from the utility.

After exhaustive measurements, analysis was done and well-engineered solution (APFC Panel) was installed.

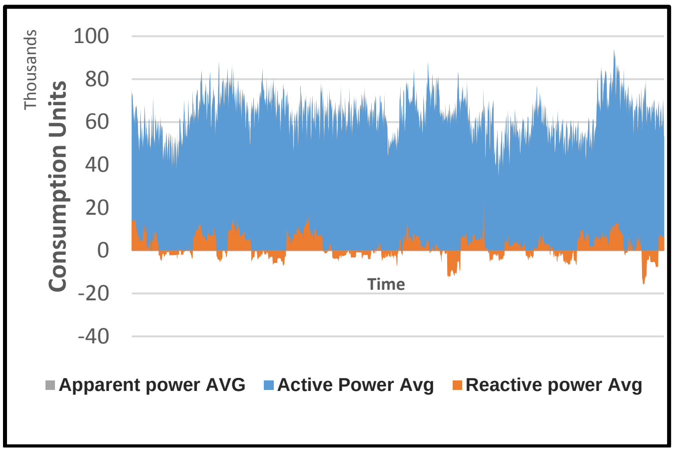


Fig-2: Variation of Active, Reactive & Apparent Power (with APFC) - Auto ancillary

Fig 2. Shows the variations after installation of APFC Panel. It can be seen the reactive power import/export from/to utility is drastically reduced.

Table-1: Summary of parameters for different months - Auto ancillary

| Parameter | Till Aug 2018 | Sept 2018 | Nov 2018 (With APFC) |
|---|---|---|---|
| kWh | 14476 | 14088 | 10829 |
| rkVAh lag | 1676 | 1132 | 10974# |
| rkVAh lead | 0 | **1450291↑** | **8078↓** |
| Billed PF | 1.0 | 0.01 | 0.75 |
| Incentive | 7% | **0%↓** | 0% |
| Penalty(Rs.) | 0 | **51,097/-↑** | **7,071/-↓** |

**MSEDCL has reduced incentive/penalty by 50% from Sept 2018 [4].*

*#Note that APFC panel was installed in the mid of November, hence increased rkVAh is due to non-availability of compensation in first 15 days.*

Case study No. LT - 2

Consumer details:

1. Type of industry: Furniture Manufacturer
2. Contract demand: 50 kVA
3. Highest kVA MD in last 12 months:46 kVA
4. Connected kVArs: 80 kVAr (in fixed mode)

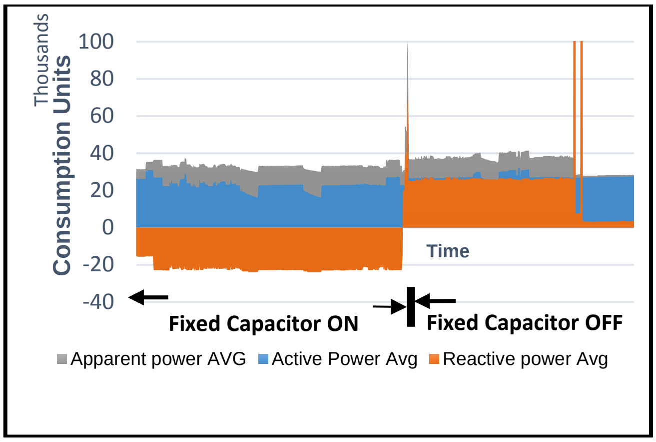


Fig-3: Variation of Active, Reactive & Apparent Power (with Fixed Capacitors) - Furniture Manufacturer

From the above graph it can be seen that even during full load due to excess capacitors ON, reactive power is being exported. After switching off all the fixed capacitors, kVArs were imported from the utility.

Table-2: Summary of parameters for different months - Furniture Manufacturer

| Parameter | Till Aug 2018 | Sept 2018 | Nov. 2018 No corrective actions |
|---|---|---|---|
| kWh | 6154 | 6402 | 5669 |
| rkVAh lag | 4 | 4 | 1255 |
| rkVAh lead | 0 | 28203↑ | 14258↑ |
| Billed PF | 1.0 | 0.220↓ | 0.34↓ |
| Incentive | 7% | 0%↓ | 0%↓ |
| Penalty(Rs.) | 0 | 18992↑ | 14059↑ |

Case study No. LT - 3

Consumer details:

1. Type of industry: Rubber oil seal manufacturer
2. Contract demand: 90 kVA
3. Highest kVA MD in last 12 months: 109 kVA
4. Connected kVAr: APFC - 90 kVAr

Intelligent APFC system was installed in the Feb 2012. Till August 2018, the consumer's power factor was consistently unity and he received maximum possible power factor incentive.

In spite of changes in calculations of billing power factor in September 2018, this consumer is receiving maximum possible power factor incentive unity power factor.

Table-3: Summary of parameters for different months - Rubber oil seal manufacturer

| Parameter | Aug 2018 | Sept 2018 | Nov 2018 |
|---|---|---|---|
| kWh | 29565 | 31677 | 26950 |
| rkVAh lag | 1203 | 1296 | 1357 |
| rkVAh lead | 0 | 920 | 907 |
| Billed PF | 1.0 | 1.0 | 1.0 |
| Incentive | 7% | 3.5% | 3.5% |
| Penalty(Rs) | 0 | 0 | 0 |

## HIGH TENSION CUSTOMERS:

### Case study No. HT - 1

Consumer details:

1. Type of industry: Rubber Industry
2. Contract demand: 2500 kVA
3. Highest kVA MD in last 12 months: 1704 kVA
4. Connected kVArs: 1100 kVAr Auto + Manual (LT), 200 kVAr (HT)

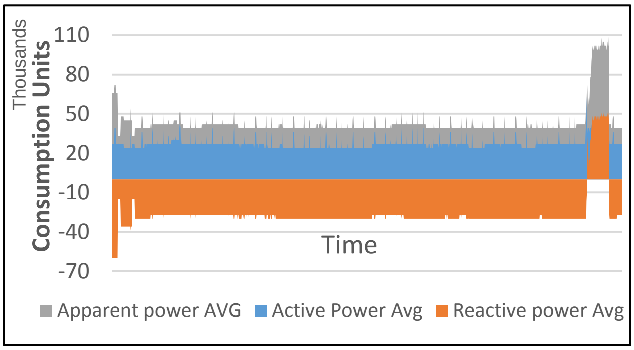


Fig-4: Variation of Active, Reactive & Apparent Power (with APFC) - Rubber Industry

Measurements were done on HT side (22 kV). It can be seen that due to overcompensation reactive power is being exported. At the end when fixed capacitors were switch-off system started importing reactive power from the utility with an abrupt increase in apparent power.

Table-4: Summary of parameters for different months - Rubber Industry

| Parameter | Aug 2018 | Sept 2018 | Nov 2018 |
|---|---|---|---|
| kWh | 509160 | 523545 | 482355 |
| rkVAh lag | 22845 | 29430 | 78375 |
| rkVAh lead | 0 | 213165🡅 | 17685🡇 |
| Billed PF | 1.0 | 1.0 | 0.98 |
| Incentive | 7% | 0%🡇 | 1.5%🡅 |
| Penalty(Rs) | 0 | 0 | 0 |

### *Case study No. HT - 2*

Consumer details:

1. Type of industry: Forging Industry
2. Contract demand: 1431 kVA
3. Highest kVA MD in last 12 months: 1629 kVA
4. Connected kVArs: 200 kVAr (Fixed) + 750 kVAr APFC Panel (75 X 10 steps) + 300 kVAr APFC Panel (25 X 12 steps)

Measurements were done on LT side for different load conditions – it was observed that reactive power was being exported due to overcompensation by fixed capacitors. The same was drastically reduced by the modifications (after mid of November) of single APFC panel of 750 kVAr - installation of four quadrant relay and introducing 50 kVAr step, rest all capacitors in auto as well as manual were completely removed from the system.

Table-5: Summary of parameters for different months - Forging Industry

| Parameter | Aug 2018 | Sept 2018 | Nov 2018 After corrective actions |
|---|---|---|---|
| kWh | 454704 | 451819 | 384406 |
| rkVAh lag | 7548 | 10688 | 40620 |
| rkVAh lead | 0 | 42570🡅 | 22729🡇 |
| Billed PF | 1.0 | 0.99 | 0.99 |
| Incentive | 7% | 0%🡇 | 2.5%🡅 |
| Penalty(Rs) | 0 | 0 | 0 |

## 3 DISCUSSIONS

It is the opinion of the authors that consumers are targeting unity power factor (billed power factor) without understanding the facts of import and export of reactive power and measuring principle of utility billing meter.

Lack of availability of measurement advanced electrical parameters in industry, concepts and latest trends related to power quality issues, authors observed that there is – major confusion in billing and the reason blame game between consumers and utility. It is need of the hour to have friendly relation between utility and consumer and there should be transparency and simplification in billing.

Use and selection of traditional thumb rules for fixed capacitors are outdated now and even application of fixed capacitors need detailed analysis and engineering.

If the maximum possible incentive received by the consumers over last few years were properly invested in automation of reactive power, such complications of billed power factor with respect to import and export of reactive power could have been avoided.

Extreme care should be taken while selecting switchgear, control gear, minimal and tamper-proof features, and display of important parameters like lead and lag kVAR with import and export of reactive power – four quadrant preferred, before installing APFC systems. It is high time to focus on management of reactive power instead of power factor. Location of current as well voltage sensing should be correct.

There should be thorough 3-phase power and energy measurement to understand and take in to account full load variation with the requirement of reactive power for different load conditions. There should be involvement of academia for survey study and analysis and measurement. This will help to bridge the gap between industry and academia. There is a strong need to update/refresh the technical knowledge of the concerned technical team to make them aware of the impending challenges such as power quality issues. Academia can play a vital role in this. No solution should be designed without measurement, study and detailed techno-commercial analysis – this is especially applicable to LT consumers.

## 4 CONCLUSIONS

In this paper different case studies of reactive power import/export and related bill issues are discussed. On-site measurements were carried out using Class A - Power Quality Analyser. The analysis of the different electrical parameters indicates that consumers are targeting power factor instead of reactive power management to get the incentives. Due to lack of recording capability and or ignoring of export of reactive power by the utility customers were overcompensating the electrical system.

It is high time to shift the focus from power factor management to reactive power management. The utility needs to have transparent billing system and educate the consumers before implementing it. The consumer should have strong Energy Management System (EMS) to monitor the important electrical parameters at PCC as well as main panels. Due attention should be given while selecting the features of the multi-function meters - such as accuracy class, availability of important electrical parameters (similar to billing meter) communication facility, ability to record import and export of electric power etc. In order to measure and analyze important electrical parameters, it is imperative to have a user-friendly software- preferably cloud-based. It would be ideal to get monthly actionable MIS report from this EMS so that targeted solutions can be implemented to conserve energy and reduce electricity bill.

## 5 REFERENCES


[1] Wolfgang Hofmann, Jurgen Schlabbach, Wolfgang Just, "REACTIVE POWER COMPENSATION - A PRACTICAL GUIDE", John Wiley and Sons, First Edition 2012

[2] Angelo Baggini, Handbook of Power Quality, John Wiley & Sons 2008

[3] MAHAVITARAN, 2016, *Technical specification three phase four wire CT / PT operated 0.5 s class, 1 amp or 5 amps fully static AMR compatible TOD tri – vector net energy meter as per category "c" of is: 15959 / 2011 for use of HT consumer*, < https://www.mahadiscom.in/consumer/wp-content/uploads/2018/03/Tech-specs-of-1A-5A-HT-Consumer-Meter-Category-C-0.5-S-Meter-Net-22.01.2016.pdf>, pg. 6.

[4] MERC, 2018, *Mid-Term Review Petition of Maharashtra State Electricity Distribution Company Limited for Truing-up of Aggregate Revenue Requirement (ARR) of FY 2015-16 and FY 2016-17, Provisional Truing-up of ARR of FY 2017-18 and Revised Projections of ARR for FY 2018-19 and FY 2019-20*, < http://www.mercindia.org.in/pdf/Order%2058%2042/Order-195%20of%202017-12092018.pdf>, pg. 487.