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Technical Note

Power Factor

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Abstract : *This note describes theory of Power factor of the system, causes of low power factor in distribution and discusses remedies/steps which a electrical engineer can take to improve performance. This note additionally contains information about a project for improvement of Power factor at PRL main campus with due consideration for technical and administrative factors during 1999-2000.*

Theory of Power Factor

Power in resistive and reactive AC circuits

Consider a circuit for single-phase AC power system, where a 230 volt, 50 Hz AC voltage source is delivering power to a resistive load as shown below (Fig. 1A)

ZR = 60 + j0 Ω or 60 Ω ∠ 0°

$I = \frac{E}{Z}$

From above I		=230V / 60 R
Hence	I	=3.8 Amp
Further	P	=(3.8)* (3.8)* 60 = 880 w

Fig. 1A: Power in a resistive circuit

In this example, the current to the load would be 3.8 amps, RMS. The power dissipated at the load would be 880 watts. Because this load is purely resistive (no reactance), the current is in phase with the voltage, and calculations look similar to that in an equivalent DC circuit. If we were to plot the voltage, current, and power waveforms for this circuit, it would look like the Figure below.(Fig. 1B)

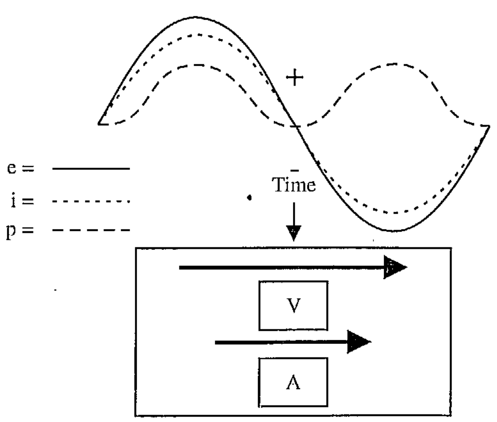


Fig. 1B: Current in phase with voltage in a resistive circuit

The wave form for power is always positive, and is never negative for this resistive circuit. This means that power is always being dissipated by the resistive load, and never returned to the source as is with reactive loads. Also the waveform for power is not at the same frequency as the voltage or current. Rather, its frequency is double that of either the voltage or current waveforms.

The best way to proceed with AC power calculations is to use scalar notation, and handle any relevant phase relationships with trigonometry. (Fig. 2B Vector diagram)

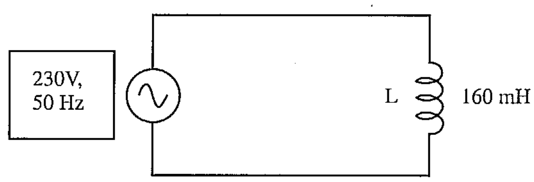


Fig. 2A A.C in purely inductive circuit

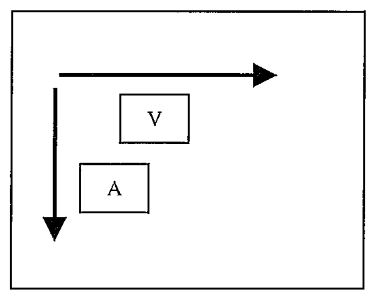
XL = 2 x 3.14 x 50 x 160mH
= 50.3 ohms

ZL = 0+j 50.3 ohms

I = E/Z

I = 230/ 50

I = 4.6 Amp Here P = (406) x (4.6) (50)
= 1060 Watts



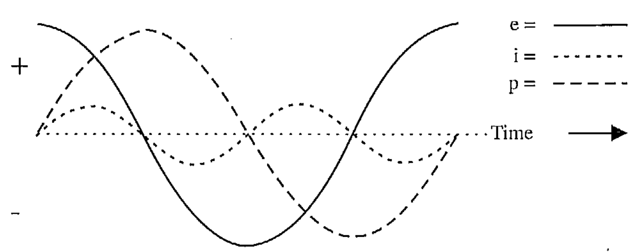


Fig. 2B: A.C in purely inductive circuit

Here current lag behind voltage wave form by 90 degree. The power alternates equally between cycles of positive and negative. This means that power is alternately absorbed from and returned to the source. (Fig. 2B Waveform)

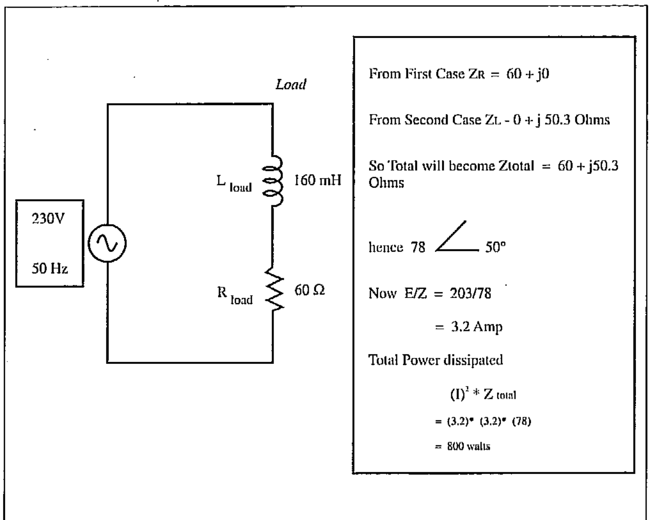


Fig. 3: A.C in combined inductive and resistive circuit

We already know that reactive components dissipate zero power, as they equally absorb power from, and return power to, the rest of the circuit. Therefore, any inductive reactance in this load will likewise dissipate zero power. The only thing left to dissipate power here is the resistive portion of the load impedance. If we look at the waveform plot of voltage, current, and total power for this circuit, we see how this combination works. In Fig. 4

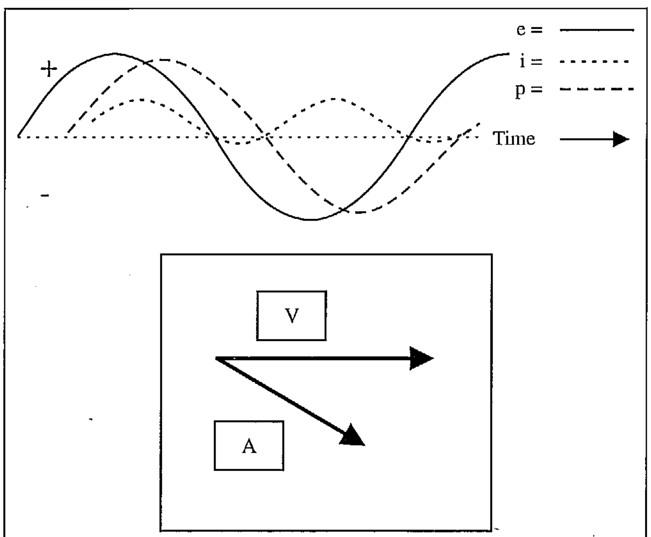


Fig. 4: Wave form for Voltage and current in combined circuit

1. The current lags behind voltage wave form not exactly by 90 degree, and (Fig. 4, Vector diagram)
2. The waveform for power is always positive, for this resistive circuit. This means that power is always being dissipated by the resistive load (resistive circuit)
3. The power alternates equally between cycles of positive and negative. This means that power is being alternately absorbed from and returned to the source. (inductive only)
4. However, in circuits with mixed resistance and reactance like this, the power waveform will alternate between positive and negative, but the amount of positive power will exceed the amount of negative power. In other words, the combined inductive/resistive load consumes more power than it returns back to the source.
5. Now if we consider a pure capacitor circuit, the current drawn by circuit will lead the voltage curve by 90°. Here also power alternates equally between positive and negative half of the cycle so there will be no net absorption of power.

Power Triangle and Power Factor Calculations

We know that reactive loads such as inductors and capacitors dissipate zero power, yet the fact that they drop voltage and draw current gives the deceptive impression that they actually do dissipate power. This "phantom power" is called reactive power, and it is measured in a unit called Volt-Amps-Reactive (VAR), rather than watts. The mathematical symbol for reactive power is the capital letter Q. (Fig: 5). The actual amount of power being used, or dissipated, in a circuit is called true power, and it is measured in watts and symbolized by the capital letter P. The combination of reactive power and true power is called apparent power, and it is the product of a circuit's voltage and current, without reference to phase angle. Apparent power is measured in the unit of Volt-Amps (VA) and is symbolized by the capital letter S.

Hence

P (True Power) = $(I)^2 x R$ or $\frac{(E)^2}{R}$ measured in watts W

Q (Reactive Power) = $(I)^2 x\ X_L$ or $\frac{(E)^2}{X_L}$ measured in VAR (Reactive Volt Ampere)

S (Apparent Power) = $(I)^2 x\ Z$ or $\frac{(E)^2}{Z}$ measured in VA (Volt Ampere)

Now consider this equation for calculation of above variables for different circuitries as seen earlier.

Purely Resistive Load:

$P = [\,(I)^2 x (R)]$
$[(3.8)^2 \times (60)] = 866\ W$

Purely Inductive Load

$Q = [\,(I)^2 \times (X)] =$
$(4.6)^2 \times 50 = 1060\ Var$

Combination

P= $[I^2R]$ Hence square of
$(3.2)^2 \times 60 = 614$ watts

Q = $(I^2) \times (X)$ hence square of
$(3.2)^2 \times 50 = 512$ Var

X = $(I^2) \times (Z)$ hence square of
$(3.2)^2 \times 78 = 800$ VA

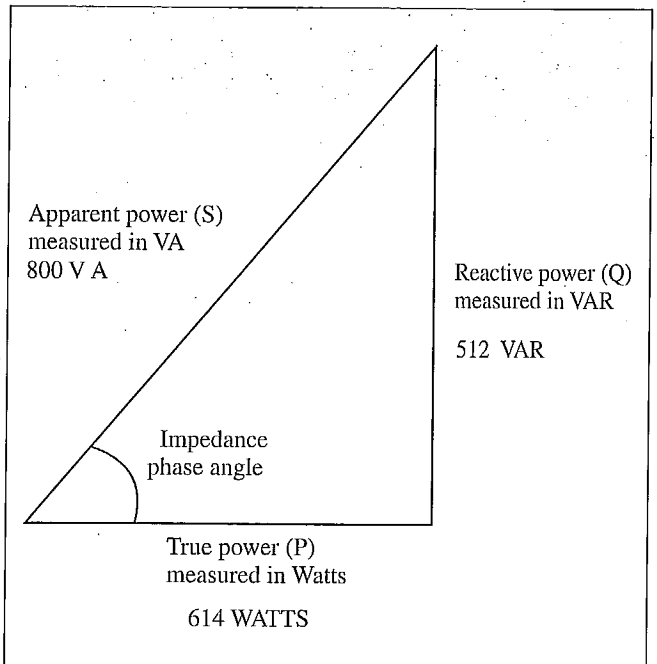


Fig. 5: The power triangle

true, reactive and apparent power are relate in trigonometric form as shown in Fig. 5 . This is know as the power triangle Using trigonometry, we can solve for the length of any side (amount of any type of power), given the lengths of the other two sides, or the length of one side and an angle.

Power Factor

The ratio between true power and apparent power of this power triangle is called the power factor for this circuit. Because true power and apparent power form the adjacent and hypotenuse sides of a right triangle respectively, the power factor ratio is also equal to the cosine of impedance phase angle.

From simple trigonometry we can say that

$$\text{Power Factor} = \frac{\text{True Power}}{\text{Apparent Power}}$$

Hence $= 614/800 = 0.75$

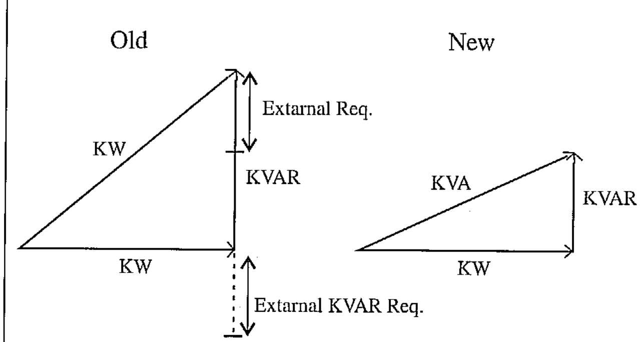
$$S = \sqrt{(P^2 + Q^2)}$$

It should be noted that power factor, like all ratio measurements, is a unit less quantity. For a purely resistive circuit, the power factor is 1, because the reactive power equals zero. Here, the power triangle would look like a horizontal line, because the opposite (reactive power) side would have zero length. For a purely inductive circuit, the power factor is zero, because true power equals zero. Here, the power triangle would look like a vertical line, because the adjacent (true power) side would have zero length. The same could be said for a purely capacitive circuit. If there are no dissipative (resistive) components in the circuit, then the true power must be equal to zero, making any power in the circuit purely reactive. The power triangle for a purely capacitive circuit would again be a vertical line (pointing down instead of up as it was for the purely inductive circuit).

Power Factor Correction

Poor power factor can be corrected, paradoxically, by adding another load to the circuit drawing an equal and opposite amount of reactive power, to cancel out the effects of the load's inductive reactance. Inductive reactance can only be canceled by capacitive reactance, so we have to add a capacitor in parallel to our example circuit as the additional load. The effect of these two opposing reactance in parallel is to bring the circuit's total impedance equal to its total resistance (to make the impedance phase angle equal, or at least closer, to zero; Fig. 6)

Since we know that the (uncorrected) reactive power is 512 Var (inductive), we need to calculate the correct capacitor size to produce the same quantity of (capacitive) reactive power. Since this capacitor will be directly in parallel with the source (of known voltage), we use the power formula which starts from voltage and reactance:



Vector diagram explaining amount of captive requirement

From above $Q = [(E)^2] / X_L$

$512 = (240) \times (240) / X_C$

$X_C = 240 \times 240 / 512$

$= 112.5$ Ohms

Now $X_C = \frac{1}{2\Pi FC}$ so $C = 1/2\text{x}3.14\text{x}50\text{x}112$

Hence it will be 30 micro farad

Correction

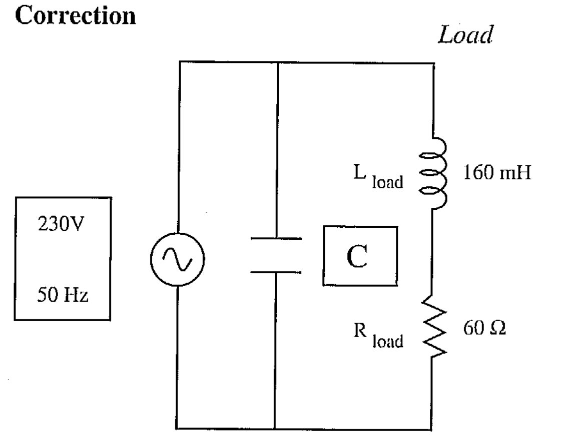


Fig. 6: Capacitor in parallel to combined circuit to improve P.F.

In practice, it is difficult to know Henry of a Inductor but today instruments like a Load Analyser are available which can measure of KW, KVA, KVAR, Hz, V,A and P.F. of a load.

Power Factor Improvement

Causes of Low Power Factors in T and D System

In general inductive load is responsible for low power factor of system. Some are described here for reference. These are purely inductive loads and are essential in many applications during these days.

Induction Motors : Generally Induction motors have low lagging power factor due to its magnetizing current Power factor of motors is very poor during light load and about 0.8 to 0.9 during full load

Power Transformers / Isolation Transformers / Welding Transformers: Similar to A.C Induction motors these are also a part of inductive load in distribution system due to its magnetizing current

Arc Lamps, Electric discharge lamps: Due to requirement of A.C choke for limiting a.c inrush current in lighting application , these equipments are also responsible for low P.F. in the circuit.

Heating Furnaces, Rotary Converters and Commutator motors

Disadvantages of Low Power Factor

Effect on Generators/ Power Transformers

1. Due to low power factor the KW capacity at same KVA rating is lowered
2. Consider two cases where a 150 KW load operates at 0.8 and 0.9 P.F.) on a diesal generator.
3. From Power triangle , KVA required will be ~ KW/P.F. Hence in these two cases, the KVA will be
   (1) 150/0.8 = 187.5 KVA and
   (2) 150/ 0.9 = 166 KVA

Hence at same KW load KVA rating of generator will be 166 and 187.5.

Effect On Prime Movers

When the power factor is decreased the prime mover needs to change its duty point is generator needs to generate more amount of energy in terms of KVA at same active power loading which in turn reduces its overall performance.

Effect on Transmission Line/ Power Cables

For the same power to be transmitted it has to carry more current at low PF hence the losses and hence the turn size calculation change.

Effect on Switchgears

The contact area for bus bar has to be increased to transmit same amount of Power in KW at low P.F.

Power Company

To induce consumer to keep their average load P.F. (average) as high as possible and to overcome fixed cost and running cost incurred for above points, the tariff is such a way that low power factor have a negative effect on Electricity Bills of consumer. Electrical suppliers consider average P.F. for billing purpose and calculate it as follows.

Average P.F.

This is computed as (Unit Consumed / KVAH consumed) {(Present reading- Past reading) KWH} / {(Present reading- Past reading) }KVAH

In another way tariff is formulated on the basis of KVA base tariff and KW base tariff.

KVA Basis

According to power triangle (Fig. 5), KVA also includes effect of reactive power (i.e. it is a vector sum of active power and reactive power of circuit) which is responsible for low average power factor of load to system. In this tariff, the Installer has to pay excess amount at same active power consumption as this tariff charge cost in per KVAR basis.

KW Basis

In this case they charge for poor power factor separately, .hence installer have to give additional cost per unit consumed per percentage of low P.F. This amount varies according to the level of average power factor of installation

Methods of Power Factor Correction

Here , methods for improving Power Factor are narrated

Synchronous motors : When a Synchronous motor is over excited it takes leading current hence works as a condenser. Further its excitation can be adjusted to get desired leading current. A synchronous motor running on no load is called synchronous condenser

Phase advancer : Phase advancer is an A.C exciter, connected to rotor circuit of motor and is mounted on same shaft of A.C motor. It provides exciting ampere turn to the rotor circuit

By Installation of Static Capacitor: This is the most simplest method of improving P.F. of load to system. Here Static capacitors are connected in parallel to lagging P.F. apparatus.

Method of installation of Static Capacitors i.e. option (C) have edge over these two methods because of

- They operates at low losses as there is no moving parts in this
- Their Initial cost is very less compared to alternate (Page 12)

- They require the least maintenance as compared to alternate (Page 12)
- They are versatile in nature and introduction of APFC panels make them more popular.

Location of Power Factor Improvement Apparatus

Power factor improvement apparatus should be installed near the equipment/machinery responsible for Low PF

For installing Phase Advancer/Synchronous motors for improvement of P.F of transmission line they should be installed near the receiving end. Installation of fixed (static) compensation at load terminal of phase reversal apparatus are to be avoided. Static power factor correction must not be used when the motor is controlled by a variable speed drive or inverter. It should not be used when motor is performing inching, jogging application or it is a two speed motor. Static power factor correction capacitors should not be connected to the output of a solid state soft starter. When a solid state soft starter is used, the capacitors must be controlled by a separate contactor. The capacitor contactor is only switched on when the soft starter output voltage has reached line voltage. Many soft starters provide a "top of ramp" or "bypass contactor control" which can be used to control the power factor correction capacitor contactor.

Bulk Compensation

Capacitors connected at a distribution board and controlled independently from the individual starters is known as "Bulk Correction". The Power factor of the total current supplied to the distribution board is monitored by a controller which then switches capacitor banks in a manner that it maintains a power factor better than a preset limit (typically 0.90). Ideally, the power factor should be as close to unity as possible. There is no problem with bulk correction operating at unity, however correction should not be applied to an unloaded or lightly loaded transformer. If correction is applied to an unloaded transformer, then a high Q resonant circuit is created between the leakage reactance of the transformer and the capacitors and high voltages can result. Further, rating of bulk compensation can be found out from standard graph attached here with. For this, the multiplying factor is determind by matching existing PF of installation with required PF on graph. this multiplying factor multiply existing Load in KW with this M.F to get value of Bulk Compensation. (Fig. 8)

Static Compensation

Power factor correction is achieved by the addition of capacitors in parallel with the connected motor circuits and

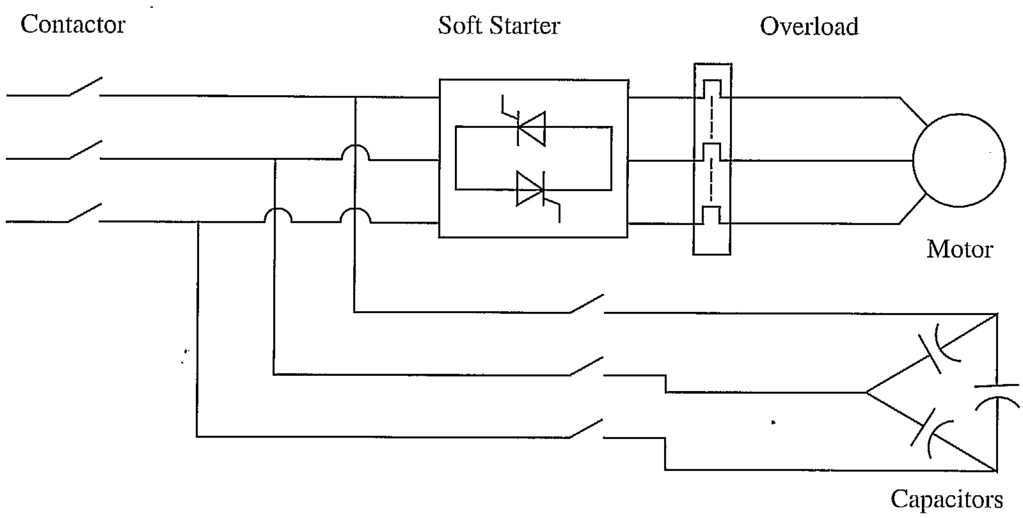
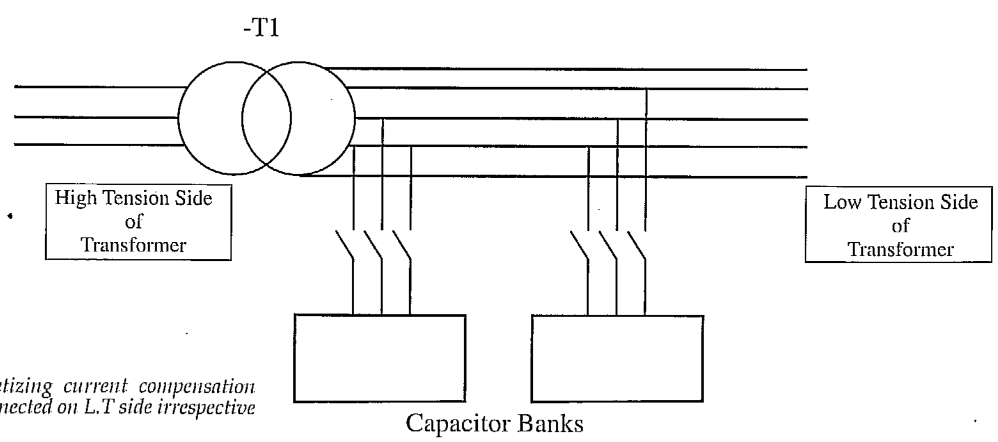


Fig. 7: Delta connected capacitor bank used as static compensation



N.B: For Transformer magnetizing current compensation 3phase capacitor banks are connected on L.T side irrespective of metering side

Fig. 8: bulk compensation

can be applied at the starter, or applied at the switchboard or distribution panel. The resulting capacitive current is leading current and is used to cancel the lagging inductive current flowing from the supply, Fig. 9)

As a large proportion of the inductive or lagging current on the supply is due to the magnetizing current of induction motors, it is easy to correct each individual motor by connecting the correction capacitors to the motor starters. With static correction, it is important that the capacitive current is less than the inductive magnetizing current of the induction motor. In installations employing static power factor correction, the correction capacitors are connected directly in parallel with the motor windings. When the motor is Off Line, the capacitors are also Off Line. When the motor is connected to the supply, the capacitors are also connected providing correction at all times that the motor is connected to the supply. This removes the requirement for any expensive power factor monitoring and control equipment. In this situation, the capacitors remain connected to the motor terminals as the motor slows down. An induction motor, while connected to the supply, is driven by a rotating magnetic field in the stator which induces current into the rotor. When the motor is disconnected from the supply, then for some time, a magnetic field associated with the rotor. As the motor decelerates, it generates voltage out its terminals at a frequency which is related to its speed. The capacitors connected across the motor terminals, form a resonant circuit with the motor inductance. If the motor is critically corrected, (corrected to a power factor of 1.0) the inductive reactance equals the capacitive reactance at the line frequency and therefore the resonant frequency is equal to the line frequency. If the motor is over corrected, the resonant frequency will be below the line frequency. If the frequency of the voltage generated by the decelerating motor passes through the resonant frequency of the corrected motor, there will be high currents and voltages around the motor/capacitor circuit. This can severely damage the capacitors and motor. It is imperative that motors are never over corrected or critically corrected when static correction is employed.

Static power factor correction should provide capacitive current equal to 80% of the no load current which is essentially the open shaft current of the motor. The magnetizing current for induction motors can vary considerably. Typically, magnetizing currents for large, two pole machines can be as low as 20% of the rated current of the motor while smaller low speed motors can have a magnetizing current as high as 60% of the rated full load current of the motor. It is not advisable to use a "Standard table" for the correction of induction motors giving optimum correction on all motors. Such tables lead to under correction on most motors but can also result in over correction in some cases. Where the open shaft current can not be measured, and the magnetizing current is not quoted, an approximate level for the maximum correction that can be applied can be calculated from the half load characteristics of the motor. It is dangerous to base correction on the full load characteristics of the motor as in some cases, motors can exhibit a high leakage reactance and correction to 0.95 at full load will result in over correction under no load, or disconnected conditions.

Static correction is commonly applied by using a contactor to control both the motor and the capacitors. It is desirable to use two contactors, one for the motor and one for the capacitors. Where one contactor is employed, it should be up sized for the capacitive load. The use of a second contactor eliminates the problems of resonance between the motor and the capacitors.

Similar to Bulk Compensation, standard table for static compensation required for motors are also available in the market. According to rating of machine like H.P, and R.P.M, compensation can be found out directly, (enclosed Table for ready reference).But as stated earlier this value generally leads to over/under compensation of equipment most of the time.

Harmonics

Supply Harmonics

Harmonics on the supply cause a higher current to flow in the capacitors. This is because the impedance of the capacitors goes down as the frequency goes up. This increase in current flow through the capacitor will result in additional heating of the capacitor and reduce its life. Harmonics are caused by many non linear loads, the most common in the industrial market today, are the variable speed controllers and switch mode power supplies. Harmonic voltages can be reduced by the use of a harmonic compensator, which is a large inverter that removes the harmonics. This is an expensive option.

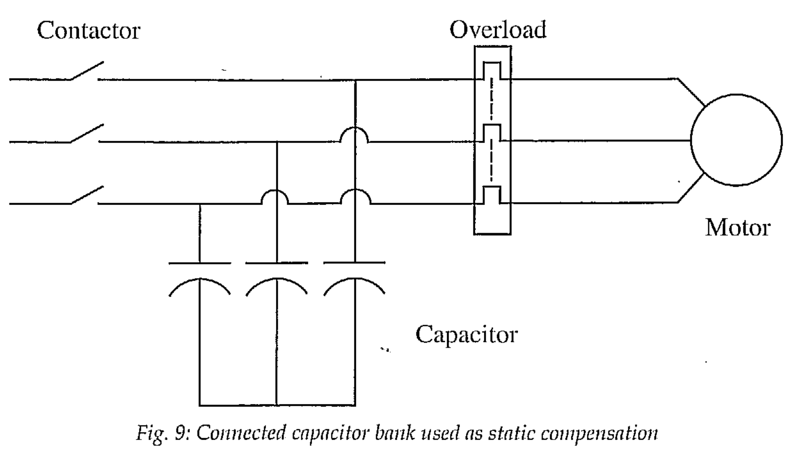


Fig. 9: Connected capacitor bank used as static compensation

Passive harmonic filters comprising resistors, inductors and capacitors can also be used to reduce harmonic voltages. This is also an expensive

In order to reduce the damage caused to the capacitors by the harmonic currents, it is "it is common today to install detuning reactors in series with the power factor correction capacitors. These reactors are designed to make the correction circuit inductive to the higher frequency harmonics. Typically, a reactor would be designed to create a resonant circuit with the capacitors above the third harmonic, but sometimes it is below rated capacity.

Detuning Reactors

Detuning reactors are connected in series with power factor correction capacitors to reduce harmonic currents and to ensure that the series resonant frequency does not occur at a harmonic of the supply frequency. The reactors are usually chosen and rated as either 5% or 7% reactors. This means that at the line frequency, the capacitive reactance is reduced by 5% or 7%. Using detuning reactors results in a lower impedance, increasing the current, so the capacitance will need to be reduced for the same level of correction. When detuning reactors are used in installations with high harmonic voltages, there can be a high resultant voltage across the capacitors. This necessitates the use of capacitors that are designed to operate at a high sustained voltage. Capacitors designed for use at line voltage only, should not be used with detuning reactors. Suitability of the capacitors for use with line reactors before installation needs to be established.

Supply Resonance

Capacitive Power factor correction connected to a supply causes resonance between the supply and the capacitors. If the fault current of the supply is very high, the effect of the resonance is minimal, however in a rural installation where the supply is inductive and have high impedance, the resonances can be severe resulting in major damage to plant and equipment.

Voltage surges and transients of several times the supply voltage are not uncommon in rural areas with weak supplies, especially when the load on the supply is low. As with any resonant system, a transient or sudden change in current will result in the resonant circuit ringing, generating a high voltage To minimize supply resonance problems, a few steps that can be taken, are given below.

Steps For Minimising Transient

1. Minimize the amount of power factor correction, particularly when the load is light. The power factor correction minimizes losses in the supply. When the supply is lightly loaded, this is not such a problem.

2. Minimize switching transients. Eliminate open transition switching - usually associated with generator plants and alternative supply switching, and with some electromechanical starters such as the star/delta starter.

3. Switch capacitors on to the supply in lots of small steps rather than a few large.Switch capacitors on o the supply after the load has been applied and switch off the supply before or with the load removal.

APFC Panel

Correction of PF by APFC Panel

APFC Panel Overview

A load and therefore its KVAR are generally in a dynamic state. A matching KVAR output of a capacitor bank must also be dynamic i.e. must adjust itself-instantly to its requirement, if one is to obtain a uniform and set PF all along. This is best achieved by an automatic control that switches in and out, segments of a designed capacitor bank. A control panel serving this purpose is called on APFC (Automatic Power Factor Controlling panel). It controls the load power factor by sensing various available parameters.

Due to complex nature of transient nature of supply system it is advisable to keep as much as capacitor KVAR out of the APFC control as possible, for example, the first step i.e. load portion which is constant on a 24 hour basis, Continuous working industries are offered static compensation.

In the second step - divide the remainder in a number of steps. Keep this number of step as small as possible, by studying the load pattern. The portion that is likely to be operated often, should be at the fag end. Large size contactors or separate contactor should be provided for long life and less maintenance

Components of APFC Panels

1. Capacitor bank step (section) i.e nos. of steps and sizes.
2. Discharge resistance on individual capacitor unit - external.
3. Incoming switch fuse for the bank.
4. Capacitor bank bus bar.
5. Capacitor bank, Current Transformers.
6. Thermal overload-relay / MCB / sectional fuses.
7. Automatic control relay & P.F. meter. Time delay relays.
8. Power contactor.
9. Push Button set / toggle switch for auto-manual function
10. Indicating lamps.
11. Cabinet (capacitor bus bars)
12. Earthing bus bars.
13. Auto-manual change over switch.

A discharge resistor on a capacitor reduces the residual voltage on it - after being switched off to a safe value of 50 volts within less than a minute and readies it for re-switching should this be required. If this resistance were to burn out, the re-switching will take place against a charged unit. This will bum it out. It is there for essential to periodically check the condition of these externally mounted discharge resistance's.

Working Principle of APFC Panel

APFC panels are operated by intelligent microprocessor based relays and can be divided in to several groups according to sensing parameters and methods of switching of these relays. Some of these are highlighted here for ready reference.

Sensing Relay based system

Current Based Sensing Relay

The current magnitude through a feeder or bus is sensed and fed to a relay. As this magnitude crosses a set band width, the relay operates a power controlling a section of a capacitor bank. This is the simplest and possibly the cheapest relay. It has the disadvantage of functioning with no reference to the actual load power factor - but by assuming it.

Power Factor Based Sensing Relay

This relay senses the start of the voltage current wave forms on a given feeder and measures the time difference between them. It then converts this into a P.F. and compares this with a set value. Upon finding a difference, it operates the power contactor. This type of relay is most widely used. It has an advantage of being able to show the laod P.F. on an indicating meter.

The disadvantages are that it has no relation to the load magnitude and the KVAR requirement. This can lead to severe hunting and may damage the network.

KVAR based sensing relay

This relay senses the magnitudes of both the voltage and current wave forms and also the time or phase difference between them. It then calculates the load KVAR and compares these with a possible combination of sections within a capacitor bank and operates their controlling contractors to add the required capacitor KVAR to the electrical system. This is the most sensitive relay capable of obtaining maximum benefit out of a given capacitor bank.

The disadvantages are that it cause stress on the contactors and its related surge suppression attachments.

Switching based system

Methods of Switching In and Switching Out of contactor bank

When the bank is controlled in equal steps, said below some designers prefer a first -in, first - out FIFO/ First-in, Last Out FILO method so that all contactors and banks have uniform period of operation & can last longer.

Methods above, calls for random switching which requires careful selection of power contactors/Nos of steps/Sizing of banks/Co-ordination of switchgears etc. Now designers are opting out for thyrister switching - which has yet to prove it's mettle in India.

SCR based static

Capacitor panels are also available but are not used frequently due to its high fixed cost. Further they are useful as they can be switched on or off during zero crossing of wave farm to avoid in ruch.

Sizing of Capacitor Banks

1. A simple straight forward method of sizing the capacitor blocks would be to divide them equally into targeted number of steps. Besides simplicity it has an advantage of standard sizes for replacement of work out contractors, blown fuses etc. Many a designer favour this.
2. In ambitious method of sizing the blocks, they are designed in a binary sequence so that a large number of combinations is available for a given set of contactors etc. If the accessories are chosen properly, this can be an ideal method though slightly costlier than method (a) above.

Trouble Shooting for APFC Panels

1. Wrong connections to the Automatic Relay

   The C.T. feeding this relay is the mains CT & not the CT within the panel itself. The voltage connection to the relay should be from the same phase from which the current is measured. These relays are single phase relays.

2. Too narrow a band-width, per step

   The band-width can be set manually. A narrow band width leads to hunting between steps.

3. Contactor points welding together

4. Discharge Resistor &/or choke coils burning out Failure of electronic components
   i. This could be due to inadequate cooling of panel, needs to provide cooling fans and fins if required,

   ii. Frequent operation of capacitor banks

5. Loose cable joints & similar causes commonly found.

6. Unattended leaks on capacitors

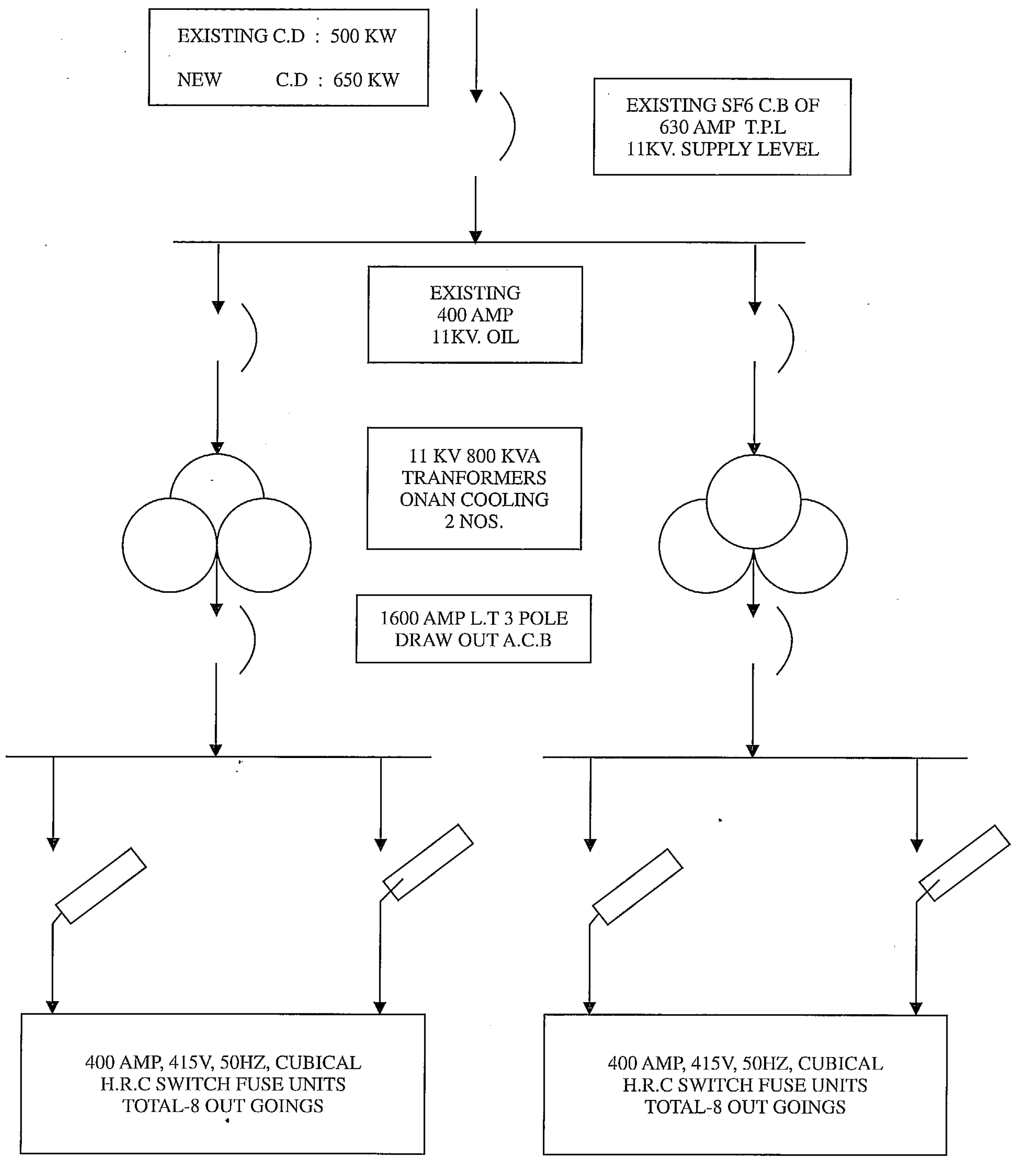


Fig. 10: Case Study of PRL Main Campus Line Diagram of High Tension Substation, HT 195

Details of Existing Switchgears of Main Campus *(Ref. Fig. 10)*

Main Campus H.T-195
Trans Former-I

Kirlosker Make

H.V : 11000v		L.v : 433V
No : 9009950		
H.V : 39.37A		L.v : 1000A
Type of Cooling	:	On
Frequency	:	50 Hz.
Impedence Volt	:	4.98%
Vector Group	:	Dyll
Oil Weight	:	932 Kg.
Total Weight	:	3925 Kgs.
Year of Manu.	:	1969
Transformer No.	:	67 KD-014/02
Specification	:	I.S 2026-1962
Max Temp. Rise	:	45 Degree

O.C.B-I

Heavy Electricals (I)

Type	:	BVP.3
Voltage	:	11Kv
Current	:	400 Amp
Frequency	:	50 Hz

Transformer-II

Kirlosker Make

H.V : 11000v		L.V : 433V
H.V : 42 A		L.V : 1067.2A
Type Of Cooling	:	On
Frequency	:	50 Hz.
Impedance Volt	:	4.94%
Vector Group	:	Dyll Oil
Weight	:	640 Kg.
Total Weight	:	2970 Kgs.
Year of Manu.	:	1980
Vector Group	:	Dyll
Transformer No.	:	78kd-080/10
Specification	:	I.S 2026-1962
Max Temp. Rise	:	45 Degree
Oil Weight	:	640 Kg.

O.C.B-II

Voltage	:	11Kv
Current	:	400 Amp
Frequency	:	50 Hz.

1 H.T service of PRL main campus(H.T-1 95) have a 650KW contract demand
2 Main H.T grid circuit is terminated at Sulphor Hexa Flouriode (SF6) Cirucuite Breaker of Torrent Power Limited, installed in substation
3 From this power is tapped to two nos. oil circuit breakers of PRL
4 Further this 11KV supply power is stepped down to utility level i.e. 415V five wire system by two numbers. Kirlosker power transformers having 750KVA and 800KVA rating respectively are used and are major sources of low power factor at PRL
5 Further power is distributed to various PCCs, MCCs through L.T panel installed in substation

Power Factor Correction Methods used before-2000

Bulk Compensation done in HT-195

During early days a APFC panel of 300KVAR capcity and having 3 phase delta connected capacitor banks (6 units of 50 KVAR each)as bulk compensation were installed at secondary side of Transformer-I. This APFC panel was working on principle of First In Last Out/First In First Out as discussed earlier (see Page: 8)

One line diagram of HT system showing location of 300KVAR APFC panel is referred for analysis (see Page 9) Installation of 300 KVAR APFC Panel at Secondary of 750 KVA Transformer (Fig.10)

Details of Old APFC panel: (Used as Bulk Compensation)

Main Input : 400 amp cubical SFU unit of L&T

Logic Controller : FIFO/FILO type with three phase voltage reference and single phase current feed back through C.T

Capacitors : 50 KVAR 3 phase Delta connected bank with discharge resistors. Total nos. of units connected are 6

Type of Correction : Bulk i.e. at Transformer Secondary side

Facts:
1. C.D of this service was 650KW against total installed load of about 1400KW
2. Load profile of this service state that Actual load of service varies according to Winter, Summer and monsoon seasons and also in day and night time. As major load of service is Air conditioning, Billing demand

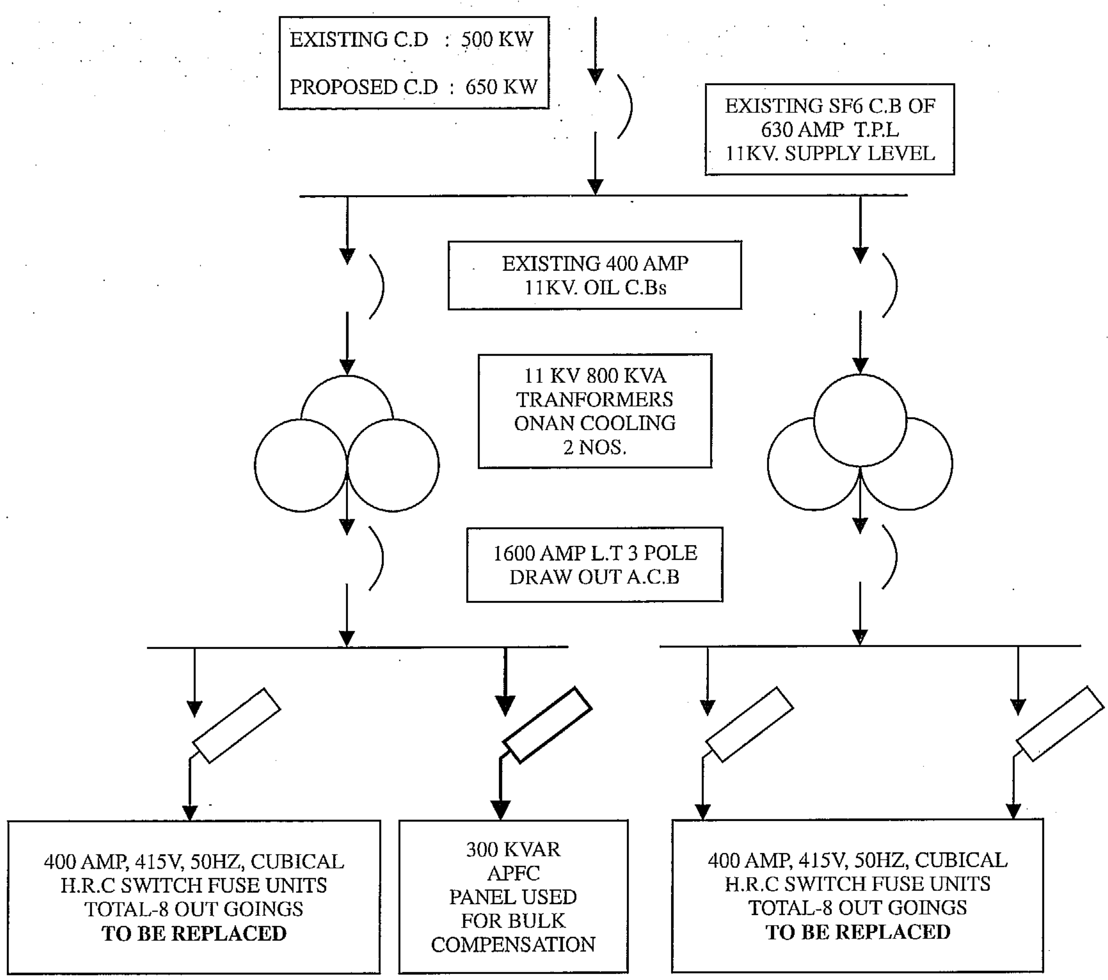


Fig. 11: details about Bulk Compensation during 1990-2000 at P.R.L. H.T.-195

was maximum during Summer (about 525KW to 550KW) and the least during winter (about 225KW to 250KW).

3. During those days average PF of the system without any external PF improvement system was about 0.75 to 0.80, Thus system's KVA and KVAR loading is as follows

Calculations: (see Page:8)

1. At 550KW and 0.8 P.F.
   KVA of System: 550KW/0.8=700KVA (for existing system)
   KVAR of System: $\sqrt{\{[700]^2-[550]^2\}}$ hence 425 KVAr

2. Similary at 550KW and at 0.85 P.F.,
   KVA : 650 and KVAR : 350

So to improve PF from 0.8 to 0.85 which was minimum required those days , we had to install total 75 KVAR capacitor bank at same load i.e. 550 KW i.e. 425 - 350= 75 KVAR. Hence considering future expansions of H.T-195 total 300KVAR Capacitor bank was installed at transformer secondary. (Fig:11)

Amperage calculation KVAR of Capacitor Current
KVAR = $\sqrt{3}$ x Voltage x Current.
Hence for 300KVAR = $\sqrt{3}$ x 0.415 x I hence I=420 amp

Limitations

Now consider a case where we need to switch on 30 to 35 KVAR Capacitor bank to maintain instantaneous PF at 0.85 of this service.

1. Minimum rating of Capacitor bank of old APFC panel was 50KVAR
2. Type of Logic Controller available in old APFC panel was FIFO/FILO.
3. Here both requirements were not satisfied hence there was a case of over or under compensation most of the time.
4. In resent years technology improved rapidly so now intelligent relays as described earlier (i.e KVAR base, see Page:8) can be used. More over small capacity power capacitors in APFC panels can be installed according to load requirements to get optimum result, as was done in Mt. Abu.
5. Still as these equipments are using three phase star or delta connected static compensation technology it is very difficult to get correct compensation in a 5 wire system having single phase loads, as in the Main Campus.

Power factor methods used after 2000

During early 2000 The Ahmedabad Electricity Co. (A.E.Co.) introduced a scheme to improve PF of the consumer services by leasing Capacitors on rent. According to this scheme their representatives examining consumer premises and suggesed to install fixed compensations and APFC panels at load points according to requirements.

The main advantage of this agreement was that investment for these costly equipments was needed once, TPL was charging these amounts in monthly electricity bills in two parts.

1.	Fixed Part	:	One time installation cost (only once)
2.	Running cost	:	Lease rent amount (monthly)
3.	Tax	:	4%S.T(extra)

According to the scheme governed by Ahmedabad Electricity Co. currently known as Torrent Power Ltd. , their energy auditors visited the site, took power readings at the main supply point, transformer ends, MCCs and PCCs, Starters by load analyzer and registered instantaneous V, A, P-F, KW and KVA.

After detail analysis they provided a report which stated size and type of compensation required for various load points. It includes transformer secondary sides, M.C.Cs for Central Air conditioner Plant, P.C.Cs for Lighting and Starters for various motors, etc.

Considering these we requested AE Co. for power factor audit at H.T-195. They submitted a design sheet stating sizing and location of APFC panels/ fixed capacitors along with financial statement. According to their statement we needed total 204 KVAR fixed compensation and 120 KVAR APFC units at H.T-195 to improve P.F up to unity. (see table-1)

Before entering in to contract with TPL, comparision of all available alternatives were done as follows.

1. TPL Lease Rent Scheme - (Alternative-1)
2. Out Right Purchase of Capacitors and APFC panels-(Alternative-2)

Alternative-1 / Lease Rent Scheme

Fixed Cost

Rs.26,000/- was shown as one time installation cost for above units which includes supply, installation, testing, commissioning, of necessary switchgears

Running Cost

Rs.12/- per KVAR i.e. (Rs.12x204) equals Rs.24487- as lease rent amount for fixed compensation and as discussed it will be charged through monthly electricity bill of HT-195

Rs.35/- per KVAR i.e. (Rs.35x120) equals Rs.4200/- as lease rent of APFC panels and will be charged in monthly electricity bill of HT-195

This amount excluded service tax charges (4%).

Lease Period

According to agreement total lease period was 5 years for this scheme

Maintenance

As per terms they had to maintain these APFC panels and fixed capacitors for five years. During this free maintenance period we observed more break downs in APFC panel installed for west wing in comparison to APFC Panels installed at east wing, central wing, Low Tension side of power transformer-1 and fixed capacitors installed at various load points.

Thus, for lease rent scheme financial implication for five years was as follows

Lease Rent Scheme

Fixed Cost:	Rs. 26,000/-
Running Cost:	Rs. 6,600/-
Service tax at a rate of 4%	
so now running cost +S.T. amount:	Rs.6900/-
Total Cost for 5 years will be 60 x 6900	Rs. 4,15,000/-

Out Right Purchase of Capacitors

Fixed Cost:	
Cost for Capacitor:	
Rs.200/ Kvar so for 204 Kvar it was	Rs.40,800/-
Cost of APFC panel: Rs.1200/ Kvar	
so for 120 Kvar it was	Rs.144000/-

In lease rent scheme, maintenance cost of these equipments are avoided thus saving was considered for comparison.

Placing 10% of material cost i.e about Rs. 20,000/year as labour charges for maintenance the total cost became Rs. 1,00,000/- for five years.

There fore total cost for comparision will be
Rs. 40,800/-+Rs.1,44,000/-+Rs.1,00,000/- = **Rs.2,88,000/-**

Selection Mode

Though we were giving Rs. 1,27,000- (i.e.Rs. 4,15,000-Rs. 2,88,000) more in Lease rent scheme, same was selected due to following reasons.

1. In lease rent scheme they would maintain this equipment for five years.

2. Further we were paying about Rs. 25,000/-(see Page-14, Table-2) per month as an excess amount to TPL for accounting low P.F of this service so we entered in to contract with TPL immediately.

As such schemes are not available else where in India we recommended the following during selection of various alternates.

Calculation for Payback Period

Saving: Advantage in excess payments

Cost: Fixed cost:
(a) Cost of Equipment (for general usage it should be total cost)
(b) Installation Cost (here actual and is one time)

Running Cost:
(a) Cost part related to fixed loss of capacitor bank per KVAR (0.3 to 0.4 watts/Kvar)
(b) Maintenance cost

After entering in to contract, M/s Saha Sprague Limited installed total 204 KVAR fixed capacitors and 4 Nos. APFC panels of 30 KVAR each at various load points i.e. L.T side of Main Power Transformer, M.C.Cs , P.C.Cs starters of motors etc. (see Table 3,4)

During static compensation at motor terminals/ starter ends they installed power capacitors and following steps were taken.

1. Overcompensation at motor terminals was avoided (Pls. compare standard compensation required by specific motor and installed capacity of device i.e. Page 24 with)
2. Installation of any fixed compensation at lift motors due to its phase reversal charecteristic was avoided.
3. Installation of fixed compensation at Inverter Drives/Soft starters etc was avoided.
4. 4 nos. APFC panels of 30 KVAR each ,were installed at following places
5. 30 KVAR at secondary of Transformer-I as static compensation
6. 30 KVAR capacity APFC for E.W, W.W and C.W of multistoried building.

Numerous of Steps and compensation were provided through APFC panel and we selected 4 steps APFC panel having 2.5,5,10 and 12.5 KVAR rated banks. This was designed according to our requirements as we have varying load on system. During morning and evening the load on system decreases rapidly so supply voltage increases at same rate. This in turn increases magnetizing current and hence causes low P.F of load. Here we have a complex situation of load and increasing lagging P.F so compensation required is exactly opposite to normal working hours.

Data sheet showing Type, Size and Location of Compensation. (see Page: 18,19)

Technical details of APFC panels:

Main	:	100 Amp three pole MCCB
Bus Bar	:	100 amp electrolytic copper bus bar for capacitor banks
Protection	:	16 to 32 amp T.P, 'C' type, M.C.Bs for each Capacitor bank
Contactors	:	32 amp Three Pole capacitor duty Contactor for each bank
Capacitor	:	M/s Sprague make oil/gas filled self healing type 3 phase capacitor banks with discharge resistors
C.T	:	50/5 amp C.T which can operate in region between its Knee point and ankle point with maximum lead of 5 mtrs.
Relay	:	Beluk make Automatic Power Factor Controlling relay
Drawing	:	see Page: 20, 21, 22

Maintenance

Frequent breakdown in the western wing was due to varying nature of load at this wing. i.e. Single Phase and pulsating in nature A.C units. Some observations are mentioned here for guideline

1. The Load of this wing was the maximum.
2. It was a single phase and of pulsating in nature, while microprocessor based APFC relay take reference of amperage of only one phase and provided all three phases so the compensation per phase was not reliable.
3. Further as there was rapid change in load current due to pulsating load of A.C compressors, no. of operations required (i.e On/Off and Change Over) for these banks were more due to more operations, stress on switchgears and banks of this unit was maximum.
4. Further we have varying load cycle during day and night time, load during day time is about 50% more than night time, which cause is change in supply voltage to capacitors and generate sever stress and reduces life of capacitors.

Due to success of this scheme at PRL main campus, We entered in to agreement for PRL Thaltej Campus as well as LTMD services of Vikramnagar staff quarter and two Pumping stations at PRL staff quarters. Details of these are also given below. (Table - 2)

Attachment:
1. Excess payment statement shown during approval: **Excess Payment Statement** (see Table-1,2)
2. TPL lease rent scheme: **Installation report** (see Table-3,4,5)
3. Table for selection of Fixed **capacitors for motor & Bulk Compensation** (see Table-5,6)
4. Pictures of Existing APFC panels & Static Compensation (Photographs 1 to 6)
5. Internal Drawing of APFC panels (Drawing 1 to 3)
6. Details of Manufacturers of APFC panels in India (Page 23)

Table-1. Hystery of Power Factor During 1998-1999
H.T-195 (main Campus)

SR.NO.	MONTH	P.F	EXCESS AMOUNT PAID TO T.P.L IN Rs.
1.	July- 1998	0.79	25,961.00/-
2.	August- 1998	0.80	5,683.00/-
3.	September- 1998	0.80	25,311.00/-
4.	October-1998	0.80	24,904.00/-
5.	November- 1998	0.79	27,950.00/-
6.	December- 1998	0.77	29,661.00/-
7.	January- 1999	0.75	33,756.00/-
8.	February- 1999	0.75	29,589.00/-
9.	March- 1999	0.76	26,662.00/-
10.	April- 1999	0.75	43,668.00/-
11.	May- 1999	0.79	41,081.00/-
		TOTAL	**3,14,226.00/-**

Installation Report of APFC Panels And Fix Compensations at Various PRL Campuses, Ahmedabad, Gujarat

Table-2, Lease Rent Scheme:
Joint Venture of M/s Torrent Power Ltd. & M/s Saha Sprague Ltd.

SR.NO.	LOCATION	SER.NO.	KVA APFC	KVA FIX	LEASE RENT	INSTALL. COST	DATE
1.	P.R.L MAIN CAMPUS	H.T-195	160	214	Rs.6940/-	Rs.15250/-	27/04/0 8/11/7
2.	PRL THALTEJ CAMPUS	H.T-449	80	33	Rs.3196/-	Rs.5100/-	24/03/03
3.	PRL STFF QTR. VIKRAMNAGAR	3013243	30	-	Rs.1050/-	Rs.400/-	24/03/03
4.	PRL STFF QTR Nr. IIM	810122	-	12.5	Rs.150/-	Rs.2100/-	08/04/03
5.	PRL STFF QTR. Nr.IIM	813153	-	7.5	Rs.90/-	Rs.700/-	08/04/03

PHYSICAL RESEARCH LABORATORY

SHAH SPRAGUE LTD.
AHMEDABAD
Installation Report

Phone : 6302129 Extn. : 4094/4090
Max. Demand :

Name of Consumer: Physucal Research Lab.
HT No. : 195
Contact Person : Mr. Ketan Bhavsar
Contaract Demand : 500 kw

Sr. No.	Location	Bank No.	Type	Rating	Capacitor Current	Readigns without Capacitor						Readings with Capacitor						Remarks
						Kw	PF	Kva	Kvar	V	1	Kw	PF	Kva	Kvar	V	I	
	750kva Transformer 1																	
1	On System Incomer for Tr. Compasation	1		24	31.4	251	0.84	298.7	250	405	340.3	259	0.9	208	96	409	320	
2	Main Bldg. No. 2	2	Fixed	10	13.5	18.1	0.8	23.1	12.2	407	41	17.7	0.96	18.4	3.1	408	32.2	
3	Ion Probe Bldg. Lighting	3	Fixed	8	11.2	29.3	0.67	31.7	11.6	403	44.7	20.7	0.963	22.3	4.1	405	32.1	
4	AC Package Plant	4	Fixed	3	4.4	9.3	0.71	12.9	8.9	404	18.5	9	0.83	11	6.1	404	15.5	
5	Work Shop	5	Fixed	8	11	14.9	0.62	24.1	15.1	396	35.6	16.9	0.9	19	8.2	396	27.1	
6	Blue Star AC Plant - 100hp Corpressor	6	Fixed	22	29.1	27.1	0.76	35.5	25.7	407	50.6	27.9	0.94	29.6	4.7	408	41.6	No Load Read
7	15 hp Chiller Pump	7	Fixed	5	6.7	12.4	0.81	15.3	9	415	21.3	12.6	0.95	13.4	3.9	415	18.5	
8	10hp condenser Pump 3	8	Fixed	3	4.4	8.4	0.81	10.4	6.1	415	14.5	8.7	0.95	9.1	2.5	415	12.8	
9	7.5 hp cooling fan 2	16	Fixed	3	4.4	3.16	0.47	6.3	5.5	415	8.8	3.1	0.79	4.1	2.5	416	5.9	
10	Accel Plant 60 hp copressor 1	9	Fixed	14	19.6	46	0.85	54.12	27.1	396	79.2	47.1	0.93	49.3	13.2	397	66.3	
11	10 hp copressor 2	10	Fixed	14	20.1	43.5	0.83	52.4	29.3	398	76.1	43.2	0.91	47.4	19.3	398	6.9	
12	7.5 hp cooling fan 1	11	Fixed	3	4.4	4.3	0.83	5.1	3.3	413	7.1	3.5	0.99	3.6	0.17	412	6.3	
13	connected on Main	12	Fixed	5	6.5													
14	10 hp copressor Pump 1	13	Fixed	3	4.4	6.7	0.73	9.3	6	400	13.2	7.9	0.92	8.66	3.14	401	12.5	
15	10 hp corpressor Pump 2	14	Fixed	3	4.3	6.5	0.8	8.17	4.8	400	11.6	6.25	0.93	6.7	1.4	400	9.7	
16	15 hp Chiller Pump 1	15	Fixed	5	6.9	13	0.84	15.1	8.2	407	21.5	13	0.96	13.5	3.4	407	19.3	
	Total Fixed KVAR	16 Units	Fixed	133														
17	Main Bldg. No. 3		Fixed															
18	West Wing		Fixed	30	43.1	48.1	0.88	58.1	25.3	377	84	47	0.99	48.1	7.1	380	72.1	
19	Central Wing		Fixed	30	43.2	38.2	0.88	43.5	20.1	378	70.1	37.1	0.98	48.7	8.9	377	58.4	
20	East Wing		Fixed	30	42.9	43.1	0.86	50.1	24.1	375	77	42.6	0.99	43	3.08	376	68.5	
	Total APFC Plant Kvar	12 unit		90														

Date of Installation : 27/4/2000
Lie. No. G/HT/C–335

Installed by
For Sana Sprague Ltd.

Table-3: Capacitor installation details of H.T. - 195

PHYSICAL RESEARCH LABORATORY

SHAH SPRAGUE LTD.
AHMEDABAD
Installation Report

Sr. No.	Location	Bank No.	Type	Rating	Capacitor Current	Readigns without Capacitor						Readings with Capacitor						Remarks
						Kw	PF	Kva	Kvar	V	1	Kw	PF	Kva	Kvar	V	I	
	750kva Transformer 1																	
1	On System Incomer for Tr.	18	Fixed	20	27.9	91	0.9	104	47.3	414	160	92.1	0.995	93.1	14.4	416	120	
	Compasation	SSU208/2/00	AFPC	30	42.5													
2	Liquid Nytrogen Comp 1 - 15 hp	19	Fixed	5	6.7	5.6	0.5	8.9	7.6	401	13.7	5.6	0.87	5.95	2.4	402	9.7	
	compressor 2-15 hp	20	Fixed	5	6.6	12.8	0.7	16.9	7.7	406	22.3	12.7	0.97	13.2	2.8	401	18.6	
	7.5 hp compressor	21	Fixed	3	4.2	4.4	0.7	6.1	4.4	405	8.9	4.6	0.97	4.76	1.1	405	6.8	
3	Ramnathan Auditorium 25 Hp	22	Fixed	8	10.9	13.4	0.75	17.5	11.6	410	25	13.8	0.96	14.1	4	410	20	
	Comp. 1																	
	25 hp compresor 2	23	Fixed	8	11.2	13.6	0.75	18.3	11.3	407	26	13.2	0.95	14	4.1	409	19.6	
	7.5 hp Pump 1	26	Fixed	3	4.4	5.2	0.84	6.1'	3.5	413	8.5	5.1	0.99	5.16	0.24	412	7.2	
	7.5 hp Pump 2	27	Fixed	3	4.2	4.9	0.75	6.21	3.7	413	8.7	5.1	0.99	5.16	0.69	414	7.4	
	Lighting main	24	Fixed	5	6.7													
4	Chemistry Buld.	25	Fixed	5	6.7	16	0.75	20.1	13.5	396	31.2	14.2	0.83	18.3	9.3	393	26.1	
5	AC Package Plant Main	17	Fixed	3	4.4	12.2	0.73	17.4	11.3	408	2.3	12.1	0.83	14.1	8.3	409	19.6	
		28	Fixed	3	4.3													
	Total Fixed	12 units		71														
	Total APFC Panel Kvar	1 units		30														

Date of Installation : 27/4/2000
Lic. No. G/HT/C – 335

Total Fixed Capacitor conencted 204
Total AFPC Panel Conncted 120

Installed by
For Saha Sprague Ltd.

Table-4: Capacitor installation details of H.T. - 195

Original Power Factor Percent	Desired Power Factor Percent				
	100%	95%	90%	85%	80%
60%	1.333	1.004	0.849	0.713	0.583
62%	1.266	0.937	0.782	0.646	0.516
64%	1.201	0.872	0.717	0.581	0.451
66%	1.138	0.809	0.654	0.518	0.388
68%	1.078	0.749	0.594	0.458	0.328
70%	1.020	0.691	0.536	0.400	0.270
72%	0.964	0.635	0.480	0.344	0.214
74%	0.909	0.580	0.425	0.289	0.159
76%	0.855	0.526	0.371	0.235	0.105
78%	0.802	0.473	0.318	0.182	0.052
79%	0.776	0.447	0.292	0.156	0.026
80%	0.750	0.421	0.266	0.130	
81%	0.724	0.395	0.240	0.104	
82%	0.698	0.369	0.214	0.078	
83%	0.672	0.343	0.188	0.052	
84%	0.646	0.317	0.162	0.206	
85%	0.620	0.291	0.136		
86%	0.593	0.264	0.109		
87%	0.567	0.238	0.083		
89%	0.512	0.183	0.028		
90%	0.484	0.155			
91%	0.456	0.127			
92%	0.426	0.097			
93%	0.395	0.066			
94%	0.363	0.034			
95%	0.329	Assume Total plant load is 100 KW at 60% power factor. Capacitor KVAR rating necessary to improve power factor to 80% is found by multiple KW (100) by the multiplier in table (0.583) which gives KVAR (58.3), nearest standard rating (60 KVAR) should be used.			
96%	0.292				
97%	0.251				
99%	0.143				

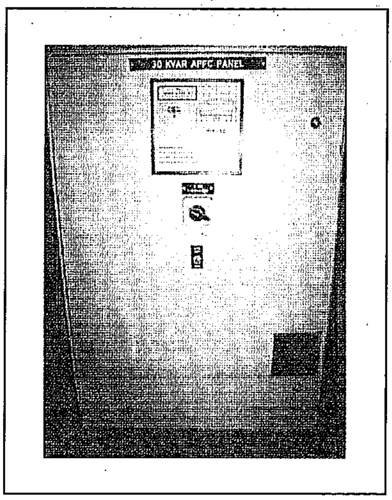
Table-5: Table Showing Selection of Capacitor For Different P.F. (Bulk Compensation)

	RPM-I	RPM-II	RPM-III	RPM-IV	RPM-V	RPM-VI
MOTOR H.P	3000	1500	1000	750	600	500
2.5	1	1	1.5	2	2.5	2.5
5	2	2	2.5	3.5	4	4
7.5	2.5	3	3.5	4.5	5	5.5
10	3	4	4.5	5.5	6	6.5
15	4	5	6	7.5	8.5	9
20	5	6	7	9	11	12
25	6	7	9	10.5	13	14.5
30	7	8	10	12	15	17
40	9	10	13	15	19	21
50	11	12.5	16	18	23	25
60	13	14.5	18	20	26	28
70	15	16.5	20	22	28	31
80	17	19	22	24	30	34
90	19	21	24	26	33	37
100	21	23	26	28	35	40
110	23	25	28	30	38	43
120	25	27	30	32	40	46
130	27	29	32	34	43	48
140	29	31	34	36	46	52
150	31	33	36	38	48	55
160	33	35	38	40	50	57
170	35	37	40	42	53	60
180	37	39	42	44	55	62
190	38	40	43	45	58	65
200	40	42	45	47	60	67
225	44	46	49	51	64	72
250	48	50	53	55	68	76

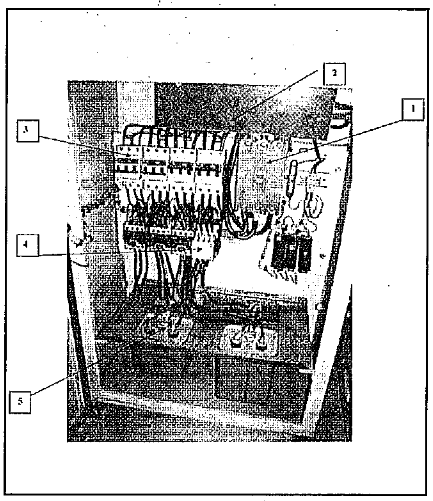
Here We can say Ns=120f/P so as speed Decreases Nos of Poles and hence Inductance of that motor will Increases. To overcome this we have to Increase Capacitor rating of same size motor from Higher RPM to Lower RPM.

Table-6: Table for determining power capacitor rating for direct connection to induction motors

Photographs Showing Details of installation of APFC & Fixed Compansation at PRL, Main Campus, Ahmedabad

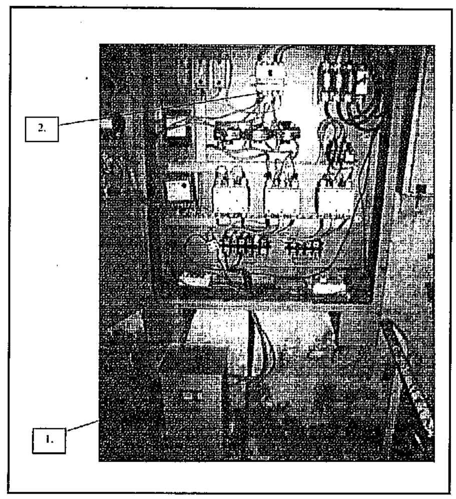


APFC PANEL INSTALLED AT MULTISTORIED BUILDING WEST WING



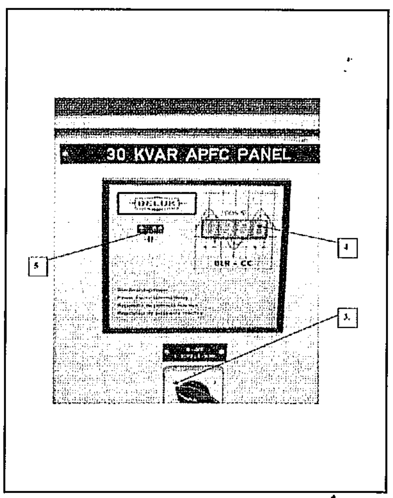
DETAILS OF APFC PANEL

1. In Comer	:	100 Amp T.p Mccb
2. Bus Bar	:	100 Amp Copper Electrolytic Tpn
3. Descrimination	:	Individual T.p Mcb For Capacitor Bank
4. Switching	:	Through Capacitor Duty Power Contactor
5. Compensation	:	P.f Duty 3 Phase Delta Conn Capacitor Bank With Discharge Resistor



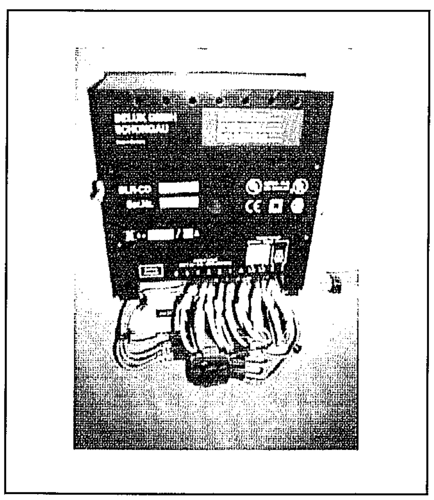
STATIC CORRECTION PROVIDED FOR STAR-DELTA PANEL FOR SUBMERSIBBLE PUMP

1. 3 Phase delta connected capacitor bank with enclosure and a tripping Device
2. Connection details : At Incomer of Star Delta Panel

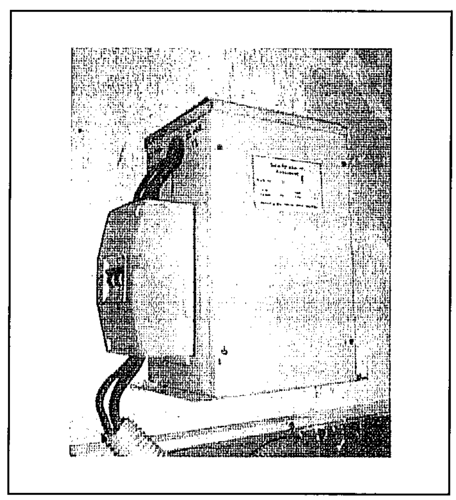


INTELLIGENT P.F CONTROLLER LOGIC RELAY

1. Make	:	Beluk, Germany
2. Type	:	Blr-cc
3. Status	:	Auto
4. Instant-taneous P.F	:	Unity
5. Bank Status	:	1,3,4 On 2 Off



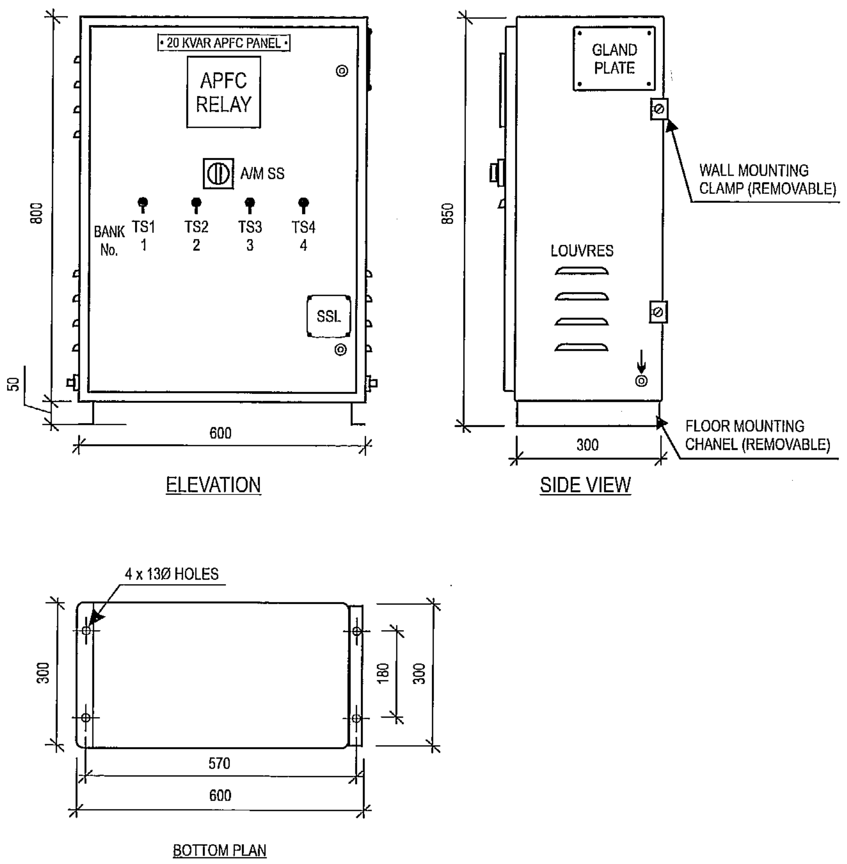
CONNECTION DIAGRAM OF BELUK APFC RELAY TYPE-BLR-CD



STATIC CORRECTION FOR SUBMERSIBLE PUMP

A3 -Phase Delta Connected Capacitor bank with enclosure and external Tripping device. Such type of Static Compensation is provided at Motor Starters, PCCs etc.

Drawing-1



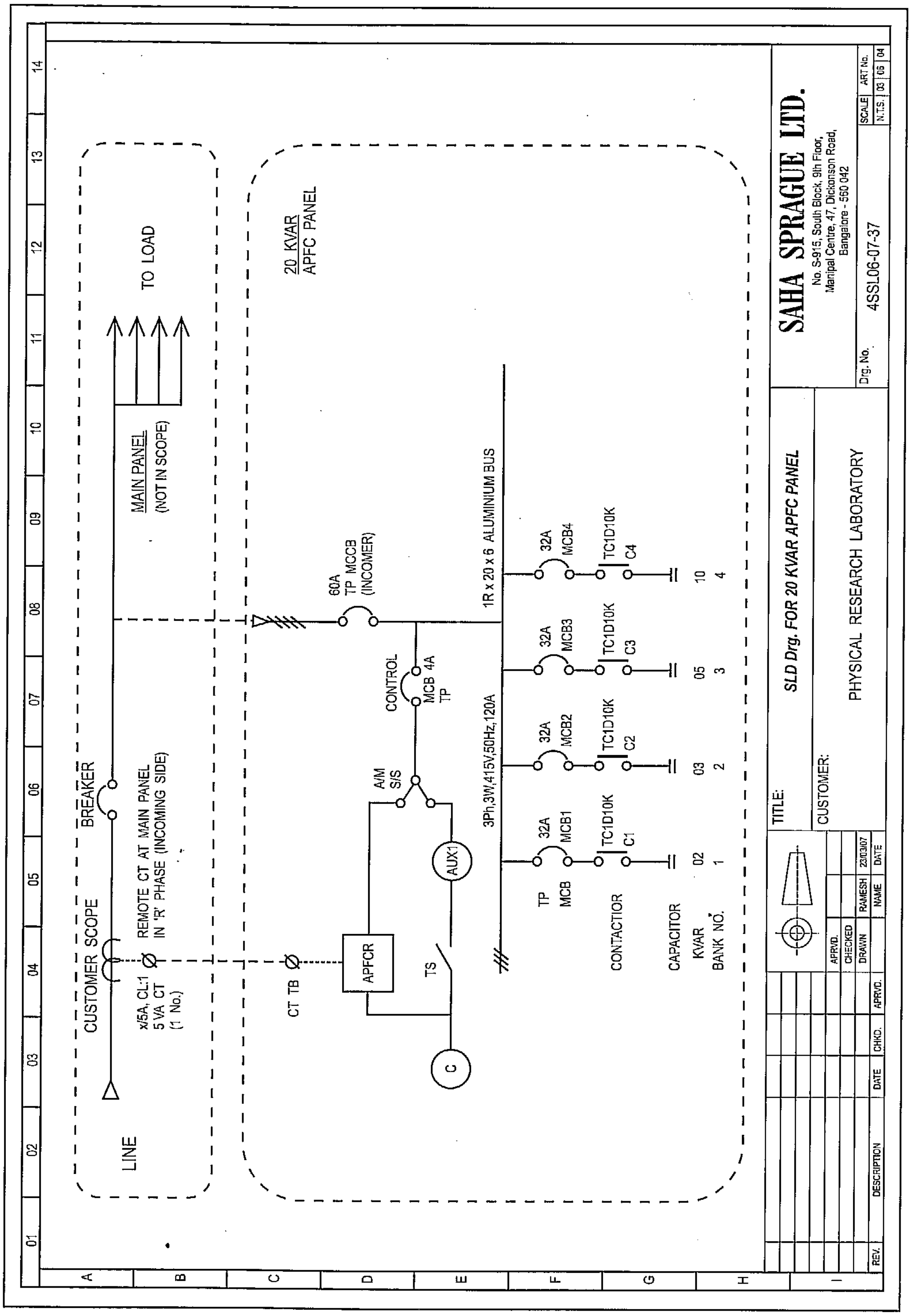
ALL DIMENSIONS ARE IN MM

REFER Sht. No. 1 FOR OTHER DETAILS

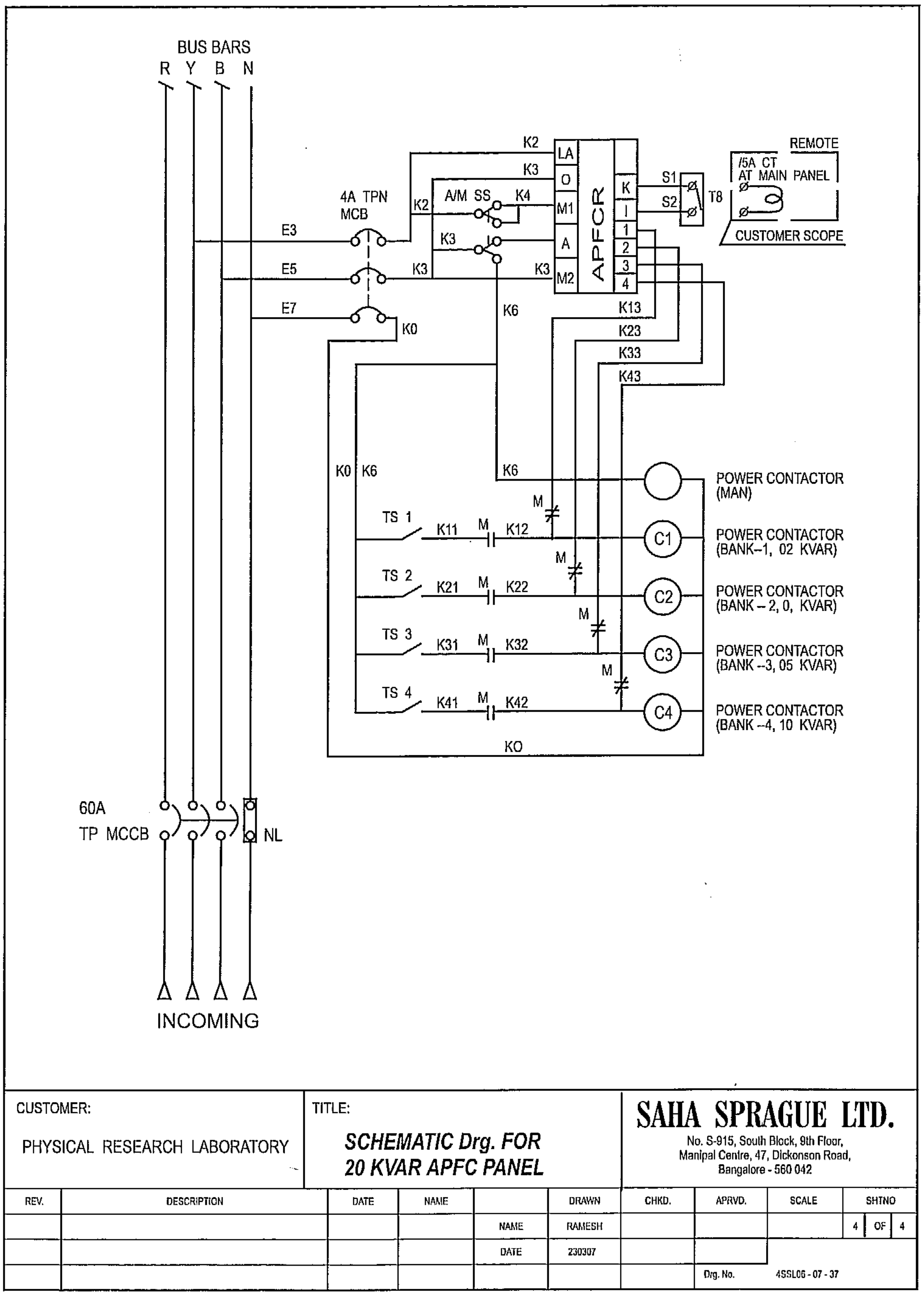
CUSTOMER: PHYSICAL RESEARCH LABORATORY	TITLE: *G. A. Drg. FOR 20 KVAR APFC PANEL*	**SAHA SPRAGUE LTD.** No. S-915, South Block, 9th Floor, Manipal Centre, 47, Dickonson Road, Bangalore - 560 042

REV.	DESCRIPTION	DATE	NAME		DRAWN	CHKD.	APRVD.	SCALE	SHTNO
				NAME	RAMESH				2 OF 4
				DATE	230307				
							Drg. No.	4SSL08 - 07 - 37	

Drawing-2


CUSTOMER SCOPE
LINE
BREAKER
x/5A, CL.1
5 VA CT
(1 No.)
REMOTE CT AT MAIN PANEL
IN 'R' PHASE (INCOMING SIDE)
MAIN PANEL
(NOT IN SCOPE)
TO LOAD
20 KVAR
APFC PANEL
CT TB
APFCR
TS
C
AUX1
A/M
S/S
CONTROL
MCB 4A
TP
60A
TP MCCB
(INCOMER)
1R x 20 x 6 ALUMINIUM BUS
3Ph,3W,415V,50Hz,120A
TP
MCB
32A
MCB1
32A
MCB2
32A
MCB3
32A
MCB4
CONTACTOR
TC1D10K
C1
TC1D10K
C2
TC1D10K
C3
TC1D10K
C4
CAPACITOR
KVAR
BANK NO.
02
1
03
2
05
3
10
4
TITLE:
SLD Drg. FOR 20 KVAR APFC PANEL
CUSTOMER:
PHYSICAL RESEARCH LABORATORY
SAHA SPRAGUE LTD.
No. S-915, South Block, 9th Floor,
Manipal Centre, 47, Dickenson Road,
Bangalore - 560 042
Drg. No.
4SSL06-07-37
SCALE
N.T.S.
ART No.
03 06 04
APRVD.
CHECKED
DRAWN
RAMESH
23/03/07
NAME
DATE
REV.
DESCRIPTION
DATE
CHKD.
APRVD.

Drawing-3


BUS BARS
R Y B N
4A TPN MCB
E3
E5
E7
K0
K2
K3
A/M SS
K4
K6
LA
O
M1
A
M2
APFCR
K
I
1
2
3
4
S1
S2
T8
REMOTE
/5A CT AT MAIN PANEL
CUSTOMER SCOPE
K13
K23
K33
K43
K0 K6
TS 1 K11 M K12
TS 2 K21 M K22
TS 3 K31 M K32
TS 4 K41 M K42
M
C1
C2
C3
C4
POWER CONTACTOR (MAN)
POWER CONTACTOR (BANK–1, 02 KVAR)
POWER CONTACTOR (BANK – 2, 0, KVAR)
POWER CONTACTOR (BANK –3, 05 KVAR)
POWER CONTACTOR (BANK –4, 10 KVAR)
KO
60A TP MCCB
NL
INCOMING
CUSTOMER:
PHYSICAL RESEARCH LABORATORY
TITLE:
SCHEMATIC Drg. FOR 20 KVAR APFC PANEL
SAHA SPRAGUE LTD.
No. S-915, South Block, 9th Floor, Manipal Centre, 47, Dickonson Road, Bangalore - 560 042
REV.
DESCRIPTION
DATE
NAME
DRAWN
CHKD.
APRVD.
SCALE
SHTNO
NAME
RAMESH
DATE
230307
4 OF 4
Drg. No.
4SSL05 - 07 - 37

Manufacturer of APFC Panels in India

- M/s L&T Switch gears Ltd.
- M/s Epcos India Pvt. Ltd.
- M/s Saha Sprague Ltd.
- M/s Unity Power Factor Controllers Pvt Ltd.
- M/s The Marsden Bakubhai & Sons Pvt Ltd.
- M/s Max Energy Pvt. Ltd.
- M/s E.S.Electronics(India) Pvt. Ltd.
- M/s Chennai Hi-Tech Engineering Pvt. Ltd.

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(3) Principles of Power System : V.K.Mehta. S. Chand and Co. Ltd., 1988 Page 1366
(4) Testing , Commissioning , Operation and Maintenance of Electrical equipments By: S.S.Rao. Page 15, 19, 150, 155 Khanna Publishers

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2. www.Bhasker power.com
3. www.Ibiblio.org

Energy Auditors

1. M/s. Sahasprague Limited
2. M/s. Pyramid Engineers
3. M/s. Seth techno consult Pvt. Ltd.

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