14 Power Factor Correction

14.1 Background
Power factor is an important consideration to ensure the efficient and effective use of electricity and also in meeting the Network Service Provider (NSP) requirements. When undertaking construction or refurbishments works, the building power factor must be considered and where it will not naturally meet the requirements of this policy, Power Factor Correction (PFC) must be installed.

This policy defines the technical requirements and feasibility assessment criteria for Power Factor Correction (PFC) installations in existing, refurbished and new buildings.

Benefits of PFC
Benefits achieved by the installation of PFC include:

a) Electricity tariff savings;
b) Avoidance of Network Service Provider (NSP) penalties for low power factor, including restricted access to more suitable tariffs (minimum of 0.9 for large and high voltage supply establishments in most states);
c) Reduced losses;
d) Reduce power drawn from distribution systems, optimum sizing of electrical infrastructure, and
e) Stabilised site voltage levels by reducing the inductive effect of the connected load.

The payback for PFC installations can be very reasonable and should not be overlooked when considering PFC for existing installations.

14.2 Performance Objective
The objective of this policy is to:

a) facilitate suitable power factor at Defence facilities and establishments, meeting the requirements of the industry regulator and Network Service Provider (NSP) and ensuring the efficient and effective use of electricity;
b) manage the impact of PFC installation to ensure no harmful effect or interaction with other installed equipment, or from other equipment to the PFC;
c) facilitate the suitable performance of PFC installations;
d) provide suitable basis for assessing the viability of installing PFC, and
e) ensure the economics of the design on a through life basis.

14.3 Reference Documents
All materials and workmanship shall be of the best standard and shall comply with the relevant legislation and Australian Standards, or if such do not exist, with the relevant IEC or International (ISO) Standards.

Irrespective of any requirements shown in this document the installation as a whole shall comply with:
Australian Standards
AS 1013-1971  Shunt Capacitors for connection to power frequency systems
AS/NZS 3000  Wiring Rules
AS/NZS 3947  Low Voltage Switchgear and Control gear
AS/NZS 61000 Electromagnetic Compatibility

14.4 Defence Requirement For Power Factor Correction

14.4.1 New Works, Upgrades and Refurbishments
Power factor correction shall be provided under the following circumstances for new, upgraded or refurbished buildings:

a) To meet the NSP requirements for minimum power factor and not to interfere with the NSP’s ripple control on the rest of their network

b) At Defence establishments with a high voltage tariff, any new, refurbished or upgraded building with a power factor less than 0.9, and

c) Where the feasibility assessment determines a worthwhile cost benefit or greenhouse reduction measure. Consideration should be given for the installation of power factor correction equipment to achieve cost savings on a maximum demand tariff. Depending on the retail arrangement, payback for the installation is generally between 1.5 to 2 years.

Where assessment of the power factor cannot confirm suitability, the PFC equipment may be omitted provided adequate space is allowed in the design of the building to incorporate PFC equipment as a future requirement. This would also apply to buildings where it would be reasonable to assume that PFC may be required at a later stage.

When allowing for future PFC installations the designer shall make all practical provisions for the installation and connection of the future PFC equipment.

Comprehensive Maintenance Services (CMS) contractor or design consultant shall monitor buildings not provided with PFC during the defects liability period to confirm suitable power factor performance. Where the performance is found to be unsuitable during the defects liability period, PFC shall be installed and commissioned prior to completion of the project.

14.4.2 Existing Installations
PFC shall be considered for existing buildings to comply with the NSP requirements for minimum power factor to avoid disconnection of supply, costly penalties, and tariff restrictions or where the feasibility assessment determines a worthwhile cost benefit or greenhouse reduction measure.

The funding of power factor correction works for existing buildings shall be in accordance with regional funding and prioritising arrangements.

14.4.3 New Equipment
Equipment performance, both individual performance and the cumulative effect of non PFC equipment needs to be considered as part of the design and also for equipment specifications. Ensure that all equipment meets appropriate standards for harmonic content and that the
equipment power factor performance is considered to avoid the need for PFC or expensive filtering in the first instance.

### 14.5 Feasibility Assessment
Feasibility assessment is to primarily address the suitability for PFC and the development of a business case to determine the financial viability.

Feasibility assessments must consider capital and through life costs of the PFC installation against the reduction in energy costs. To be viable Defence requires a simple pay back to be achieved within five years. When considering greenhouse gas reductions, use $70 per tonne for the greenhouse gas reductions achieved.

It is important to remember that poor power factor due to an inductive or capacitive load can be improved by the addition of PFC. However, poor power factor due to distorted current waveform can require a change in equipment design or expensive harmonic filters.

#### 14.5.1 Assessment Procedure
The designer needs to determine the need and suitability for PFC. Consideration of the following should be included in the assessment:

- a) What are the consequences of poor power factor in terms of energy costs and non-compliance with NSP
- b) Determine if any special conditions exist and the suitability for PFC such as existence of distortion due to electronic loads, UPS systems, power generation facilities or complex electronic loads
- c) Determining the load profile and the nature of the load in all operating modes and with all possible sources of supply
- d) Determine any power supply quality issues in terms of voltage and frequency stability
- e) Determine the nominal location, sizing and arrangement
- f) Complete the Financial Assessment
- g) For HV connection check any possible interference with the NPA’s ripple control and if necessary use series reactors to detune from these frequencies.

#### 14.5.1.1 PFC Viability Checklist
Provided below is a basic checklist for determining PFC feasibility:

- a) Is there a kVA Demand Charge Tariff from the Network Provider against which savings can be made?
- b) Is there an opportunity for greenhouse gas reductions?
- c) Will the installation of PFC achieve construction cost savings?
- d) Is the payback period less than 5 yrs?
- e) Is there a suitable location for the installation of the PFC equipment?
- f) Is the installation suitable for PFC?
g) Is there an operational or commercial reason to install PFC that overrides the economic reasons?

14.5.1.2 Review Existing for PFC implementation.
Consideration of previous Defence installations can provide valuable insight into the strategies and design principles of PFC that could be used to undertake the feasibility assessment. General aspects to consider include:

a) Location and type of PFC equipment
b) Previous supplier of PFC equipment and preferred configurations
c) Performance of existing PFC equipment including maintenance issues and downtime.
d) Equipment compatibility/suitability

14.5.1.3 Load Profile and Energy Costs
A preliminary load profile needs to be established to consider the required PFC arrangement providing the basis for determining size (kVAR). This assessment is used to determine viability, not detailed design criterion, and can achieved through any of the following:

Electricity Accounts
Review existing electricity accounts to determine the electricity tariff. There must be a kVA Demand component charge to which savings will be made or a cost penalty or tariff restriction for low power factor. If this isn’t the case, PFC should not be considered unless there are operational reasons for doing so.

The electricity accounts will provide a base line to determine the kVA Demand consumption and the electricity charges. Improving the PF to unity will reduce this charge and provide monetary savings for Defence.

Base Power Monitoring
Investigate the availability of data from the Defence power monitoring systems such as Defence Engineering Services Network (DESN), Power Control and Monitoring System (PCMS), Building Management System (BMS), Regional Utility Management Systems (RUMS) or other permanent Digital Power Analyser typically installed at Main Switchboards (MSB’s).

Maximum Demand Indicator
The Maximum Demand Indicator on a MSB can provide a guideline to the maximum current drawn but rarely will this provide sufficient information to adequately assess the PFC installation.

Measurement
The maximum demand and load profile can be measured by the use of a data logger that measures in 15 minute intervals over a 7 day period.
Assessment
For new buildings and facilities it may be found impractical to measure the maximum demand and load profile. Assessment can be made by calculation using a square metre rate of VA consumption for a building. This will give an approximate PFC Unit size.

Location and Preliminary PFC Configuration
To complete the feasibility assessment the anticipated cost of installing the PFC needs to be determined. This will involve determining the preliminary location and arrangement for the PFC including the number of load steps as this could have a significant cost impact.

Financial Assessment
The payback period is the time required for the PFC installation to redeem the cost of installation. The cost benefit analysis needs to consider the through life costs of the PFC installation against the reduced energy costs or savings in the reticulation system construction costs.

The financial assessment must confirm a simple payback is achieved within five years and must take into consideration the through life costs of the installation.

14.6 Technical Requirements
14.6.1 Objectives of PFC Design
To provide an automatically controlled PFC unit that will bring the power factor to as near to unity as practical (typically 0.97) and have sufficient capacity for future PFC requirements or expansion. The PFC shall be designed with suitable safeguards to prevent harm to the PFC from outside influences or from the PFC to the distribution system or the building services and its equipment. All power factor correction units shall have series reactors to detune the capacitance away from the harmonic frequencies and protect the capacitors from excessive harmonic currents.

It is intended that proven commercially available units be used arranged to suit semi-skilled operators.

14.6.2 Design Analysis
Suitable analysis must be undertaken as part of the design process. The minimum requirement includes detailed analysis of the load profile and harmonic analysis.

Where the installation is a new establishment and it is not possible to undertake measurement, the designer must assess the installation requirements and constraints before specifying each project element. The designer must incorporate all assumptions and assessment outcomes in the design report and must ensure that the PFC will not cause any harmful effect to the building, its equipment or the supply system.

Determination of the Load Profile
Suitable load profile assessment must be undertaken. This will normally involve three phase power recorder installed at all relevant locations but as a minimum the same location as the proposed PFC equipment. The recorder should sample VA and W every 15 minutes for at
least 7 days. This will provide the load profile for the site to allow the PFC configuration to be determined.

Wherever possible, the load profile should be taken as close a possible to the critical demand periods, however, where this is not possible the results will need to be adjusted to cater for seasonal variations.

**Consideration of Load Types**

Generally load falls into two (2) categories:

- **Load that creates lagging PF.** A lagging PF load will consist of magnetic devices that cause inductance like motors, magnetic ballasts in lights and cables.

- **Load that creates leading PF.** A leading PF load will consist of capacitive devices. Increasingly, installations containing data centres are causing a leading power factor and the PFC equipment needs to be matched to this noting that traditional capacitive PFC systems will not be able to cope with leading power factor. An alternative is the synchronous motor but this has its limitations due to de-rating under leading power factors. It is noted that a leading PF may offset the lagging PF of the rest of the site.

**Harmonic Analysis Before Construction**

The purpose of harmonic analysis is to provide a base line for existing harmonic levels within the installation and to identify where special precautions may be necessary.

This will be used for comparison against the post installation measurement of harmonic levels and ensure that the PFC is not increasing the existing harmonic levels.

It will also provide the design basis for the installation of harmonic filters to reduce harmonics to below 5% Total Harmonic Distortion (THD) and to ensure that no harmful effect or interference to any other element of the building. The harmonic analysis shall be undertaken in all operating modes and particularly with both normal and emergency power supply systems.

**Resonance**

The use of PF correcting capacitors in combination with an inherently inductive circuit can result in either series or parallel resonance or a combination of both depending on the system configuration. Usually parallel resonance occurs more often because capacitor banks act in parallel with system impedance (inductive). This can be a matter of concern if the resonant frequency happens to be close to one of the frequencies generated by the harmonic sources in the system. The result is that excessive harmonic voltages can be generated in the circuits containing PF correction units. Therefore the designer must take all necessary measures to ensure that the resonant and harmonic frequencies don’t occur at the same frequency. This will involve both design calculations and onsite assessment as part of commissioning. Due to the possible changing nature of the load over time however, all power factor correction units shall be fitted with optional series reactors to detune the capacitors away from the main harmonic frequencies. The voltage rating of the capacitors shall also be increased appropriately (normally 525 Volt minimum for low voltage installations).
14.7 PFC Requirements

14.7.1 Unit Size and Arrangement
The required size in kVAR and arrangement of the PFC steps shall be based on the load profile and the known future requirements where applicable. To allow for future increases in demand, space shall be provided to allow the incorporation of additional capacitors/inductors.

The designer shall consider the merit of installing smaller distributed units against installing one larger unit where large distances are involved between the point of connection of the PFC equipment and the load to be corrected.

It is generally preferred that PFC be installed on the low voltage system near the load to be corrected.

14.7.2 Steps/Sizing
The smaller the kVAR rating of each inductor or capacitor switched in stages, the better will be the control of the PF. This will be offset against the increase in space required for more capacitors and the cost for additional contactors. The only variation to this is for fixed duty loads (e.g. particular motor) where a single PFC step used in conjunction with the equipment is justified or more practicable.

The number and arrangement of the steps shall be to suit the profile and characteristics of the load. There shall be sufficient adequately sized steps to ensure smooth correction of power factor with minimum cycling under normal load conditions. There shall also be sufficient provision to prevent cycling of the load steps within the control system.

Unless single step arrangement for fixed load is used, load steps shall be arranged with at least one suitable half step and minimum of four steps, unless direct-coupled PFC is used for specific equipment application such as a single large motor. As a guide, for low voltage installations 25/12kVAR capacitive steps can be used below PFC units of 200kVAR and 50/25kVAR capacitive steps above PFC units of 200kVAR.

14.7.3 Location and Accommodation
An essential requirement for the positioning of PFC is that it be located near to the load to be corrected. Typically this will be at the MSB, however, where the load is more than 100 metres from the MSB or where the load is large consideration must be given to locating the PFC at the load. Distances beyond 100m will need to be checked with the PFC manufacturer to confirm suitability of the PFC as voltage performance may become a significant consideration.

Additionally, if the load is distributed over a large area consideration should be given to locating PFC at the equipment locations meaning installing smaller PFC units closer to the load to be corrected instead of a single larger unit at the source of incoming power.

Where it is impractical to install the PFC at the building, installation at the substation may be allowed subject to DEEP agreement.
It is preferable that the power factor correction equipment only correct the building load when the mains is connected and not correct the load when the local emergency generator is connected.

Allowance also needs to be made for access and maintenance activities. There shall be a minimum of 600mm clearance provided from open enclosure doors to adjacent walls or equipment. The layout of the PFC and its accommodation shall be arranged such that a failed component, such as a capacitor unit can be replaced without dismantling the unit or impacting on other components of the PFC.

The space required around PFC equipment varies depending on size and the ventilation requirements, but as a guide generally a 500kVAR unit will be 2m Wide X 2 m Height X 0.6m Deep.

Ensure adequate ventilation is provided in the room containing the PFC equipment.

14.7.4 Fire Integrity
The PFC and switchboard rooms must have fire integrity to MFPE/BCA. If the PFC equipment is installed in a switchboard room that has an emergency mode operation (e.g.: smoke exhaust equipment), the arrangement of the PFC shall be such that on failure it cannot interfere with the emergency operation of the facility.

Where necessary, this shall include suitable fire separation of the PFC from the emergency services. Any penetrations through fire compartments will need to be suitably sealed to maintain the fire integrity of that compartment as per the MFPE/BCA.

Also ensure that the PFC equipment is not mounted near critical infrastructure where a fire could cause excessive damage to these building elements.

Other Requirements
The room containing PFC equipment shall be provided with:
  a) An appropriate fire detection system suitable for the environment (normally some form of smoke detection)
  b) Emergency and Exit Lighting in accordance with MFPE/BCA
  c) Lighting levels to AS/NZS 1680
  d) A means of adequately rejecting the heat generated by the power factor correction capacitors and reactors. It should be noted that the heat generated by the reactors can be significant and some rooms may require air conditioning to achieve this.

14.7.5 PFC Configurations
There are two (2) types of PFC equipment to consider:

- **Static PFC.** Static PFC is the use of staged capacitors or inductors to adjust the Power Factor as determined by a Power Factor Controlling device. Capacitors or inductors are switched in and out to compensate for various lagging or leading PF
conditions. This is generally the system of choice for correcting PF but the use of a rotary PFC may be more practical in certain situations.

- **Rotary PFC.** A synchronous motor can be used as PFC given the right power factor control. The synchronous motor would be connected to a continuous mechanical load and the motor provided with a three (3) phase supply. As the motor runs, the excitation on the motor can be varied to provide leading or lagging PFC on the electrical supply to which it is connected. This would provide PFC at the source and would be located away from the Main Switchboard, possibly in a plant room.

### 14.7.6 Static PFC Construction

Static PFC construction shall be dead front metal clad equipment cubicle minimum Form 1 construction. The cubicle shall be suitable dust and vermin proof and shall contain:

a) Controls section housing the controller, transducers, metering and control and indicating devices;

b) Switchgear section housing the contactors and fuses; and

c) Capacitor/inductor compartment. The arrangement shall be such that the heat from the reactors does not unduly elevate the operating temperature of the capacitors, controls or switchgear.

### 14.7.7 Harmonic Performance

Harmonic loads cause additional power losses in the power supply and in severe cases the distortion can cause over heating of switchgear, transformers and motors, malfunction of voltage regulators and drop out of phase failure relays. Depending on the natural frequency of the power supply and its connected load, the system can actually resonate causing high voltage peaks and equipment damage.

Particular care needs to be taken with PFC equipment is connected to the systems with harmonic content because the capacitors can suffer from over heating due to the passage of harmonic current through them, or can suffer insulation damage due to voltage notching in the power supply caused by commutation of semi-conductors. As a precaution use “reactive” capacitors for power factor correction equipment. These have series reactors designed to impede harmonic currents and “detune” the capacitor circuit away from the main problem causing harmonic frequencies.

The PFC must be installed in a coordinated manner considering the environment the PFC will be connected and to the level of harmonics present. The designer shall ensure that the PFC design achieves the required harmonic performance and where necessary incorporates suitable harmonic filtering to protect the PFC and also to ensure no harmful effect to the installation and equipment. The harmonic filters are to detune the capacitors away from the harmonics present.

The best way to handle harmonic distortion is to treat it at the source of the harmonics and reduce the magnitude. If the background level of harmonics is already high, then consideration may need to be given to providing harmonic filters at the main sources of the
harmonic distortion to lower the background harmonic distortion sufficiently. Make the PFC supplier aware of the background harmonics as part of any specification.

14.7.8 Resonant Performance
Parallel resonance only causes problems if a source of harmonics exists at the same frequencies as the resonance frequency. To avoid this a frequency scan and harmonic resonance evaluation with calculations are required to determine the possibility of the harmonic and resonant frequency occurring at the same frequency. If this does occur, the solution is to either apply tuned harmonic filters to each offensive harmonic frequency or an appropriately sized capacitor to avoid harmonic resonance.

It should be noted that the harmonics generated, and the resonance point in the system may be different when the load is connected to a local emergency generator. Generators are generally rated to adequately supply the kVAR required by the load. It is therefore preferable not to connect the power factor correction equipment whilst the load is being supplied by the local emergency generator.

14.7.9 Transient Performance
 Capacitor switching causes voltages and current transients. The size of a transient is determined by the size of the capacitor and this is a proportional relationship. To overcome transients, a series inductor needs to be installed which will decrease the rate of change of the current transient and thereby reduce the resulting voltage transient.

14.7.10 Capacitors
**Wet Type.** Wet type capacitors are oil-impregnated capacitors. Wet type capacitors shall not be used in PFC equipment as the rupture of this type of capacitor under fault conditions may endanger the safety of Defence personnel or equipment.

**Dry Type.** Dry type capacitors don’t contain fluids and are a reduced risk under capacitor rupture. The capacitor should also have a discharge resistor to allow for discharging the capacitor when the PFC unit is turned off for maintenance reasons.

The following general capacitor performance requirements should be considered:

a) Minimum voltage of 525 V r.m.s. phase-to-phase in a single three (3) phase unit.
b) Ratings from 25kVar to 50kVar
c) Self healing type
d) Protection against internal rupture
e) Life expectancy of 10 years
f) Temperature operation range from -10°C to 50°C

14.7.11 Inductors
The primary functions of inductors are to:

a) Reduce the effects of harmonic currents on the PFC system
b) Reduce the possibility of resonance occurring in the system
c) Reduce the interference to and from possible utility supplied metering signals.
d) Life expectancy of 10 years  

e) Temperature operation range from -10°C to 50°C.

**14.7.12 PFC Controller**  
Solid state controllers shall be used to automatically control the PFC to maintain the optimum system power factor. The controller shall have automatic and manual modes. Under manual mode it shall be possible for an operator to manually select the required operation and the manual controls shall only be operable in manual mode.

The automatic mode shall be site configurable without the need to change software or hardware configurations. Appropriate hysteresis loops are to be incorporated to avoid hunting and the controller should also cycle capacitor/inductor duty.

Control and indication is required to suit semi skilled operators and there shall be sufficient indicators and meters to easily and accurately portray the state and condition of the PFC equipment.

The PFC shall share the duty between capacitors and inductors as appropriate.

**14.7.13 Defence Engineering Services Network (DESN) & Building Management System (BMS) Interface**  
The PFC controller shall incorporate sufficient monitoring and alarm outputs to allow interfacing with the DESN and/or BMS systems. The monitoring and alarms interface shall be voltage free contacts from the PFC controller. Generally monitoring shall include Auto/Manual indication, common alarm and common fault indications and power factor out of range indication.

**14.8 Contactors**  
Contactors shall be adequately rated to switch the capacitor or inductor loads. The contactors shall be rated for an electrical endurance to give 20 years life based on the anticipated switching duty. The designer must ensure a suitable duty category is specified for all switchgear to meet the above requirement.

**14.8.1 Protection**  
The PFC equipment shall be appropriately protected and shall be fail safe in operation (i.e. PFC component failure will not effect the power supply to the facility).

Each capacitive/inductor device shall be protected by appropriately rated HRC fuses and the HRC fuses are to be co-coordinated with the upstream circuit breaker. Notification of HRC fuse rupture is to be interfaced with the DESN/BMS as a common fault alarm.

The PFC shall automatically disconnect on controller failure.

The PFC shall be designed to suit the electrical system fault levels and shall include suitable harmonic drop out relays where appropriate. Harmonic drop out relays must be configured to trip and require manual reset by operator. Any alarm or fault including out of range alarm
shall be suitably monitored as a common fault on the DESN or similar where present at an establishment.

The PFC shall automatically disconnect on loss of supply and when supply return the PFC shall resume normal operation.

The provision of automatically disconnecting the PFC equipment on an inappropriate power factor is required (e.g. leading power factor for capacitor bank) and alarmed appropriately.

**14.8.2 Provision for Maintenance**

The PFC shall be configured to allow maintenance to be easily performed. There shall be suitable facilities to discharge the capacitors, labelling of equipment to indicate the presence of high voltages, and ease of access to the rear of the panel.

Consider the maintenance requirements when determining the most appropriate equipment performance specifications and system arrangement. This shall be based on the required performance, maintenance, reliability and the availability of comprehensive manufacturer’s product support locally.