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With more than two million customers, CLP Power Hong Kong Limited is the largest power utility in Hong Kong and has been providing a reliable electricity supply to its customers for over a hundred years.

Power Quality (PQ) is not a new topic of concern and is as old as the power system itself. Rapid development in power electronics and computerized equipment over recent decades has ushered in many advantages including efficiency enhancements, cost reduction and quality improvements. On the other hand, these power electronics or computerized controls demand extra care in feeding them with their electricity supply, i.e., they have a much higher PQ requirement, and are susceptible to supply voltage disturbances, voltage dips in particular. Although some fail-safe designs can work properly during power outages, unexpected or undesirable operations may be triggered as a result of voltage dips. A short voltage dip may eventually develop into a long supply interruption and the disruption of operations. Harmonics may also induce equipment damage or other potential hazards.

This handbook describes the effects of PQ problems on major types of equipment in commercial and residential buildings, such as shopping arcades and offices, and suggested possible solutions for reducing the impact of these effects.
Through our work with a wide variety of commercial and industrial customers, we have identified two common and significant types of power quality concern:

**Voltage Dips**

Typically, a voltage dip occurs as a result of a disturbance to the power system, which produces a momentary reduction in the voltage level. Voltage dips cannot be totally avoided. The major causes of these disturbances are:

- Lightning strikes
- Fallen trees
- Third-party damage

In addition to applying a high standard of system design and O&M, CLP Power has also devoted extra effort to install additional lightning protection for overhead lines, and also set up vegetation management teams. To reduce third-party
damage, we have worked with the HKSAR Government in drafting new legislation, the ‘Electricity Supply Line Protection Regulation’, which came into effect as from April 2001. The regulation carries penalties, including fines and imprisonment, and the new legislation includes a Code of Practice (COP) incorporating effective work steps for damage prevention.

**Harmonics**

Owing to their nonlinear characteristics, variable-speed drives and Direct Current (DC) machines, along with switch-mode power supplies, cause harmonic currents. These harmonic currents cause harmonic voltage distortion, which in turn can cause control malfunctions, capacitor failure, motor and transformer overheating.

![Highlight of harmonics](image)

**Take Action - Be PQ Problem Free by Planning Ahead**

Power utilities alone cannot totally eliminate the impact of these PQ issues. Regulators, manufacturers and customers need to contribute in different aspects of PQ solutions. Many PQ problems can be avoided by planning in advance before the design and purchase of new electrical equipment. It is much more cost-effective to incorporate PQ requirements
upfront to prevent potential PQ problems than it is to fix the problems after the equipment is put into service. Here are some tips when planning a new development or purchasing new equipment:

**For Mitigating the Impact of Voltage Dip**

- Practically, three levels of compatibility or combination of the three levels can be adopted for voltage dip ride-through capability according to the functionality of the equipment:

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<th>Level</th>
<th>Description</th>
<th>Example</th>
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| I     | Equipment can function properly during voltage dip (EN50160: 1% - 90% remaining for 10ms to 1 min) | • CCMS computer supplied through true on-line uninterruptible power supply (UPS).  
• Changeover or automatic transfer scheme supplied by DC control supply. |
| II    | Equipment complying SEMIF47 or IEC61000-4-11 /IEC61000-4-34 | • Contactor complying SEMI or IEC.  
• Chilled water pump with dip proof inverter to secure its control contactors.  
• Lift control equipped with inherent ride-through capability or employed DC control supply. Should the lift be tripped beyond the specified standards / ride-thru limit, it should be able to re-start automatically under normal operating condition. (II+III). |
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| III   | Equipment cannot complying Level I / II but equipped with automatic re-starting function or backup device | • Chiller auto re-started by CCMS after voltage dip.  
• Standby chiller auto started when main chiller tripped.  
• Lift could be auto restarted under post-volt-dip-operation design and return to the destined floor if the lift be tripped beyond the specified standards / ride-thru limit |

- Furthermore, regarding the ride-through requirement for escalator, reference can be made to the Code of Practice on the Design and Construction of Lifts and Escalators (2010 Edition, Section E Part 4, Clause 8.4.1.2). Similar ride-through feature and other mitigating products for lift, including ride-through feature, emergency rescue device and remote communication and monitoring system are also commercially available.

- Post-voltage-dip-operation feature for lift should come with inherent ride-through capability or other means to protect all sensitive electronic controls.
For Mitigating the Impact of Harmonics

- Equipment such as UPS, computers and motor drives will generate high harmonic current. It is recommended to request the manufacturer to conform to maximum limits of harmonic levels, according to international standards, by incorporating built-in harmonic suppressing or filtering devices.

Recommendation

- Obtain advice and suggestions from manufacturers and CLP Power. Some cases are described in the sections below. In each case, some ‘Planning Ahead Tips’ are provided for reference. If you take them into account when planning for new electrical equipment, you will be free from the trouble as described in these cases.

- Refer to international practices on ‘voltage dip ride-through capability’. Among the many sources are: the Information Technology Industry Council (ITIC) recommended capability curve, the Semiconductor Equipment and Materials International (SEMI) standards, IEC 61000-4-11 and IEC61000-4-34. An illustration is shown in Appendix 1.
Likewise, for equipment that may generate ‘harmonics’, CLP Power Supply Rules (Section 220) is a useful reference specifying the limits of harmonic emissions. An extract from the section is shown in Appendix 2.
There are usually many essential appliances on your premises. Some of them may be sensitive to voltage dip and some of them may generate harmonics. These may result in operation disruption, loss of critical facilities or even equipment damage.

1. Air-conditioners

Problem Area
In Hong Kong, air-conditioners (A/C), especially window-type A/C, are widely used electrical appliances. Most high-density high-rise buildings and some primary and secondary schools are equipped with large numbers of window-type A/C. Although they enhance the comfort of the occupants, they also create problems during voltage dips. Some customers advised that their main ACB (air circuit breaker) tripped during peak-load periods in conjunction with lightning storms or
adverse weather. Nevertheless, the supply from the power utility side remained intact during the incident.

**Investigation and Finding**

Lightning and adverse weather can cause voltage dips in the power system. During a voltage dip, the compressors of some window-type A/Cs may stall due to the sudden drop in voltage. When the voltage recovers, the A/C compressor may fail to re-start due to highly pressurized coolant remaining in the A/C refrigerating cycle. This can result in a locked rotor inside the A/C compressor. The current increases to around 3 ~ 7 times the normal value. The surge in current may in turn cause the main ACB to trip on over-current due to the simultaneous re-starting of a large number of A/C compressors. Supply interruption may then occur. The locked-rotor current may be detected by an A/C’s internal thermo protection, but the operating time of the ACB’s over-current protection is so short that the main supply will be interrupted before the thermo can operate.

Some compressors may not stall, but they still draw 3 ~ 7 times normal current value during re-starting.
If the ACB can stay on for a short period of time, this can allow the compressor’s thermo protection to cut off the locked-rotor current.

Some window-type A/C models are equipped with a feature that will cut power to the compressor instantly on a voltage dip, and then resets automatically after a time delay. This type of window-type A/C will not cause the above-mentioned problem.

**Conclusions and Recommendation**

The tripping of the main ACB is attributable to uneven load distribution, high load demand under hot weather conditions, and sudden load fluctuations during a voltage-dip incident.

For high-rise buildings:

- Supply upgrading or load diversion is proposed in order to reserve more capacity for sudden load demands and current fluctuations.

- Extremely inverse-type over-current protection relays allow a greater time margin for riding through the re-start current of the A/C compressor motor without sacrificing the reliability of the protection.
Precise estimation of load growth and close monitoring of load demand would be necessary.

For schools:

3-min Auto-restart Control Box

- Allow time for air-conditioners to reset.
- Limit the number of air-conditioners to be started simultaneously.

- Installation of a 3-minute auto-restart control box is proposed to offer additional features for the contactor for grouped control of air-conditioners. The control box will cause the contactors of all air-conditioner groups to drop off on voltage dip and switch them in again, in sequence, after a 3-minute delay.

- Supply upgrading or load diversion to allow more margins for the current surge.

Planning Ahead Tips

- Reserved capacity for load fluctuation.
- A/C or large machine-starting current under normal and voltage dip conditions.
- A/C with instant compressor cut-off on voltage dip and automatic time-delay reset.
2. Chiller Plant

Problem Area
A/C equipment, in particular with chiller plants, is widely used in Hong Kong. Records show that chiller plants and their associated equipment (control panels, chiller water pump, etc.) are susceptible to voltage dips due to intrinsic overload protection, or lack of ride-through capability in the design of their control circuitry. Although the inconvenience incurred may be minimal for customers with operations staff who can quickly restart this equipment, the impact could sometimes be significant for customers managing large shopping malls, hotels, and public transportation systems.

Investigation and Finding
It was revealed that the chiller and associated pump controls are sometimes electronic or computerized controls, and these are sensitive to voltage dips. Control contactors and these controls may drop off when the control supply voltage drops below normal magnitude during voltage-dip incidents.

Conclusion and Recommendation
Possible solutions are summarized as follows:

- Two common tactics for reducing the impact of voltage dips on the chiller plant are to allow the chiller to ride through the voltage dip and to introduce auto re-start control to the chiller. Effective solutions are to
provide on-line UPS for the chiller controls and install new software with the auto re-start control option.

- Chiller plants are sometimes wired into the building automation system. Such a system sometimes provides a customized control sequence for automatically re-starting the chiller-plant equipment during a voltage dip incident. Modification to the building automation system software of the routine scheduling program can provide a new switching sequence to achieve this target.

- A centralized control panel is another typical feature of a chiller plant. By securing its control supply through a PQ-improvement device, e.g., UPS or a dip-proofing inverter, constant running of the chiller plant can be maintained.

- Some chillers may have stringent requirements that do not permit voltage dip ride-through. They therefore trip instantly during a voltage dip. However, improving the ride-through capability of the chilled water pump can maintain the flow of cold water throughout the building. This can help to maintain the desired temperature of the building while the chiller is being restarted.

- Some chillers can cause voltage dip problem during motor starting, current limiting device should be used.

Most customers consider that the investment in and the effectiveness of the modification are fully justified in view of the benefit obtained in return. Solving the voltage-dip issue is a good example of customer involvement and excellent cooperation between customer, chiller supplier and CLP Power.

**Planning Ahead Tips**

- Reserved capacity for load fluctuation.
- Program for auto re-start for chiller plant
- Starting current control for large chiller motor.
3. Building Automation

Problem Area
BMS (Building Management Systems) are in widespread use in Hong Kong for building automation. BMS are equipped with centralized computers and distributed units (sometimes called direct digital controllers). These devices are sensitive to voltage dips. In some cases where an uninterruptible power supply (UPS) has been installed, the system still crashes occasionally during voltage-dip incidents.

Investigation and Finding
In one case, investigations revealed that the UPS was of the switched-type. A switched-type UPS, which had a slow response under marginal conditions, could cause the distributed unit/controller to hang up due to voltage fluctuations.
Moreover, too many status changes and alarms occurred during system disturbance. These also caused the BMS and associated system to hang up.

**Conclusion and Recommendation**

- It is recommended to use true on-line type UPS to secure the power supply to computer equipment.
- It is recommended to ensure / improve system performance on signal flooding.
- Scheduling program should include auto re-starting of chiller and chilled water pump after voltage dip.

**Planning Ahead Tips**

- Ensure reliability of central PC and distributed unit under voltage dip or other disturbances.
- Perform simulation of alarm flooding under system disturbance.
- Program auto re-start for chiller plant.
Problem Area
High-intensity-discharge (HID) lamps, sometimes called high-pressure lamps, are in common use. However, many of them temporarily extinguish after a voltage dip. These lamps may be installed at critical locations and loss of lighting after a voltage dip may cause inconvenience to the public.

Three types of HID lamp were tested, namely the high-pressure sodium lamp, metal-halide lamp and mercury lamp.

High Pressure Sodium, Metal Halide and Mercury Lamps - Based on voltage-dip simulation tests, these lamps cannot ride through a voltage dip below 70% (remaining) with duration longer than 50ms. Lamp re-ignition time was about 3-10 minutes.
**Investigation and Finding**

Ballast is available on the market that offers better voltage dip ride-through capability over conventional ballast.

**CWA**

Some types of HID lamp use a CWA (constant wattage autotransformer) circuit. A CWA circuit offers stable operation (brightness) under supply voltage variations, and its voltage-dip ride-through capability is better compared with conventional ballast circuit. Lamp outage due to voltage dip is minimized as the CWA ballast has a higher tolerance of voltage drops. Simulation tests identified that the lamp can sustain a voltage dip down to 40%. As voltage dips seldom drop below 50%, this level of performance is considered satisfactory.

**Universal Voltage Ballast**

Universal voltage ballast is electronic ballast that can regulate its output voltage to maintain constant intensity of the lamp. Its voltage-dip ride-through capability is better than conventional ballast circuit. Lamp outages due to voltage dip can be minimized because the ballast regulates the voltage output when there is a voltage drop. The lamp can thus sustain voltage dips of long duration down to 40%. The ballast can maintain normal output voltage to the lamp with wide input voltage range (e.g., 90-260V).
Other consideration
Sometimes the customer may use an energy-saving step-down transformer to supply low-rating mercury lamps (50W) or HID lamps used in shopping centres. As the normal output voltage of the transformer was 5% - 7% lower than 220V, these lamps would be more likely to be extinguished during voltage-dip incidents. Considered the energy-saving trend, more and more customer are switching their lighting to LED (Light-emitting Diode) floodlight. The selection of proper ballast and/or LED floodlight is more complicated and a site test may be required.

Conclusion and Recommendation
HID lamps using common ballast circuits are sensitive to voltage dip and temporarily extinguish during voltage dips. Re-ignition time is 3 to 10 minutes and this can cause inconvenience to users. It is recommended to consider the following mitigation measures to reduce the impact of voltage dips on essential lighting:

- Use lamp circuits with better voltage dip ride-through capability, e.g., using the Constant Wattage Auto-transformer (CWA) or electronic ballast circuit.
- Use lamps with a double-tube feature, where the side tube can ignite when the main tube is extinguished.
- Add hot re-strike igniter (for higher power lamps) that can produce high voltage to re-ignite the extinguished lamp.
- Use energy-saving fluorescent lamps (CFL - compact fluorescent lamp) or LED floodlight to replace high-pressure lamps with lower power rating.
• Voltage dips seldom occur on all three phases of the supply. Evenly distributing the lamps to three phases of supply reduces the chances that all lamps will extinguish after voltage dips.
• Use PQ-improvement equipment (e.g., UPS).

Planning Ahead Tips
• Provide emergency battery backup or UPS for underground car-park lighting.
• Improve voltage-dip ride-through capability of discharge lamp.
5. Lifts and Escalators

Lifts and escalators are common means of transportation for vertical and cross-slope movement. Lifts nowadays have high-speed design and large cars to meet passenger-flow demands especially in high-rise commercial buildings. Escalators also have high-speed designs to cope with passenger flow in mass-transit facilities for both down-slope and up-slope transportation.

Lifts

Problem Area

As with public transport, lifts and escalators are subject to passenger-safety concerns. The requirements on both lifts and escalators are stated in the ‘Lifts and Escalators (Safety) Ordinance’ and the ‘Code of Practice on the Design and Construction of Lifts & Escalators’ in Hong Kong.

There are around 50,000 lifts in Hong Kong (i.e., including 10,000 on Hong Kong Island, and 40,000 in Kowloon, New Territories and Lantau Island). During voltage dips, some lifts are tripped with passengers trapped inside (‘shut-in-lift’).
Investigation and Finding
Most lifts are designed to auto re-start after a voltage dip, and perform the ‘Homing’ function, which is an essential feature of the fireman’s lift. However, there are still incidents which may result in shut-in-lift due to problems with different components.

As regards mechanical parts, the possible causes are:
- Activation of mechanical safety devices, e.g., landing-door safety switches and over-speed governor.
- Upper/lower limit switch operated as a result of lift marginally overshooting when travelling towards terminal floors (G/F or roof floor).

As regards electrical parts, the possible causes are:
- Loss of memory due to temporary shutdown of computerized controls.
- Too long homing time during auto restart.
- Stalled-motor timer expired while auto re-starting in the tunnel zone (at no designated landing floor).
- Fault counter overflow.
- Fuse and control PCB blown.

Although some lifts do re-start after a voltage dip, the re-starting time may be too long with consequent misinterpretation by passengers as shut-in-lift.

Conclusion and Recommendation
Possible solutions are as follows:
- If no hidden mechanical defects, the lift should be able to auto re-start and perform the ‘Homing’ function, which is an essential feature of the fireman’s lift. Inclusion of checking of auto re-start or power loss homing function in maintenance procedures should be considered.
- If the homing time was too long during re-starting, an emergency floor opening in the tunnel zone could be modified as a landing floor for passenger evacuation. Alternatively, high-speed floor locating should be considered. Low-speed floor locating during re-start is always misinterpreted by passengers as shut-in-lift.
If the lift tripped on stalled-motor timer when the lift was repositioning itself at low speed, a sensor should be added in order to feedback running status to reset the timer. Alternatively, high-speed floor locating software should be considered.

- Mechanical defects and damaged voltage arrestors should be cleared and replaced during compulsory routine maintenance.
- Effective intercom to duty guard post is desirable (instead of relaying to un-manned machine room).
- Lift-status display lantern should be considered for comforting passengers when the lift has tripped or is restarting at low speed.
- Dynamic reactive compensator should be added to reduce voltage dip caused by starting current surge.
- Voltage dip immunity components should be considered to enhance the ride-through capability of the control circuits and/or motor drive.
- Post-voltage-dip operation (refer to the latest edition of COP on the Design and Construction of Lifts and Escalators) and ARD (Automatic Rescue Device) should be considered.
- Advanced type motor drive equipped with kinetic buffering and/or regenerative feature should be considered.

**Escalators**
Problem Area
Property management team advised that escalators were found tripped during voltage-dip incidents. In addition to requiring manual reset of all affected escalators, passengers may lose their balance and suffer injury during the sudden arrest of the escalator.

Investigation and Finding
The control contactors and PLC dropped off during voltage dips. Moreover, the phase-monitoring (PM) relay was not equipped with a time-delay setting, such that the escalator was tripped by the PM relay even though the contactors and PLC did not drop off.

Conclusion and Recommendation
- It was recommended to add an uninterruptible power supply (UPS) to secure the power to the control contactors and PLC.
- In addition, the phase-monitoring relay was replaced with a new relay equipped with a short time delay allowing the escalator to ride through the voltage dip for 0.2 sec.
- To modify the setting of the variable speed drive in order to enhance ride-through capability.
- For adding ride-through feature, please refer to latest “COP on the Design and Construction of Lift & Escalator”.

Planning Ahead Tips
- Voltage dip ride-through capability of the lift and escalator.
- Effectiveness of auto re-start or homing feature of lift under different conditions after a voltage dip.
6. Distribution Board

Problem Area
Some ACBs tripped occasionally after voltage dip.

Investigation and Finding
Several ACBs with an identical control scheme were tripped after voltage dips. The tripping was initiated by the voltage protection of the ACB control. A 2500A ACB in the main switching room was isolated for testing.

The protection circuit consisted of a 3-phase voltage sensing relay (3PVR) and a single-phase AC auxiliary (AR) relay. The 3PVR provides both under-voltage and over-voltage protection for the 2500A circuit. The trigger levels were set to ±20% with a time delay of 5 seconds. The output of the 3PVR was connected to the AR relay; both of them required additional AC control supply, which was taken from the L1-phase. Voltage dips of various magnitudes and durations were applied to the relays respectively. The salient points were as follows:

- With L1-phase voltage dip to 80V (remaining) and duration of 100-300ms, the 3PVR incorrectly tripped because it could not provide any time delay.
• With L1-phase voltage dip to 80V (remaining) and duration of 80ms, the 3PVR incorrectly tripped on ‘over-voltage’ and without any time delay.
• The 3PVR malfunctioned on any two-phase dips with L1-phase involved or 3-phase dip.
• With voltage dip applied on either L2- or L3-phase and with duration not longer than the time setting (5 sec), the 3PVR was stable.
• Similarly, with L1-phase voltage dip to 110V (remaining) and duration of 50ms, the AR tripped and gave out trip signal incorrectly.

The 3-phase voltage relay and the single-phase auxiliary relay were susceptible to voltage dips occurring on the L1-phase (control supply). They malfunctioned during voltage dips and caused the malfunction of the protection scheme.

Conclusion and Recommendation
The salient points were as follows:
• The voltage protection scheme was found to be sensitive to voltage dips.
• The AC-driven voltage relay and the auxiliary relay of the scheme might mal-operate and trip off the ACB during voltage dip. Ordinary AC timers could not provide true off-delay function. A true off-delay timer should be used instead.
• It is recommended to modify the scheme to DC scheme, adding coil hold-in device or on-line uninterruptible power supply (UPS) to secure the control supply to the protection scheme.

Planning Ahead Tips
• Use of DC scheme and equipping with battery and charger.
• True off-delay timer.
7. Change-over Scheme

Problem Area
Most estate buildings are equipped with a change-over scheme to provide alternative supply to the essential loads, e.g., public lighting, lifts, water pumps and security systems. However, certain change-over schemes may malfunction during voltage-dip incidents and result in interruption to the essential supply.

Normally, essential loads are connected to the normal supply and share the supply bus with other major loads of the residents and tenants in the estate buildings. When the normal supply is lost, the supply to the essential loads can be resumed through the operation of the change-over scheme. The ‘Normal’ breaker (CB-N) is tripped off and the ‘Essential’ breaker (CB-E) is closed to connect the essential loads to the alternative supply. The aforesaid operations are fully automatic and are initiated by the change-over scheme logic. When the supply resumes, the breakers revert to their original status. However, proper operation failed during a voltage-dip incident and caused supply interruption to essential loads.
Another property management company reported that their back-up gen-set started up for several seconds during a voltage-dip incident. Fire and security equipment alarms also came on.

**Investigation and Finding**

There was the possibility that the change-over scheme might malfunction and result in supply interruption under voltage-dip conditions for the following reasons:

- The change-over scheme employed common AC supply as control supply.
- Voltage dip with critical magnitude and duration caused the AC relays of the scheme to chatter.
- The chattering was fast enough to trip off the CB-N but the time was too short to close the CB-E.
- The scheme was equipped with time-delay operated under-voltage relay but the trip command was not effectively guarded.
The scheme could not reset itself and thus was locked off after both breakers were opened.

There was no true off-time delay to reduce the unwanted start-up of the back-up gen-set during voltage-dip condition.

The alarm control scheme for the fire and security system was AC driven.

Site inspection also revealed that the control setting of some change-over schemes was too sensitive. The over- and under-voltage setting could not tolerate minor voltage fluctuations caused by load change and switching of power-factor improvement capacitor bank. Moreover, time delay setting was found set to zero seconds.

An over-sensitive change-over scheme may divert the essential supply to the non-started back-up gen-set end during minor voltage fluctuations. This results in supply interruption although the supply from the power utility is healthy.

**Conclusion and Recommendation**

Possible solutions are:

- To employ DC supply for the change-over and other control schemes because AC-driven relays malfunctioned during voltage-dip incidents. This is similar to most fire and security systems that employ DC with battery back-up as control supply to enhance scheme reliability.
- To employ coil hold-in device to reduce the chance of relay-chattering under voltage-dip conditions.
- To employ true off-delay relay to coordinate with the under-voltage relay in order to allow a short delay.
before issuing trip signal to the respective breaker under voltage-dip conditions, or start command to back-up gen-set.

- It would be desirable to adjust the voltage setting of the scheme in order to allow sufficient margin to ignore transient disturbances which may be produced by the starting of heavy machinery or sudden load changes at the load side. The operating time setting should be long enough to ride-through most voltage dips in order to achieve higher reliability.

The best solution depends on the actual site situation. CLP Power is ready to provide consultancy services to assist customers in solving this kind of problem.

**Planning Ahead Tips**

- Reliability of the scheme under voltage dips.
- Use of DC scheme and equipping with battery and charger.
- True off-delay timer.
- Over-/under-voltage and time-delay setting of change-over scheme.
8. Computers and Servers

Computers and servers are usually supplied by an uninterruptible power supply (UPS) in order to prevent hanging, lock-up or resets resulting in data loss due to voltage fluctuations.

Problem Area
There are two types of UPS in the market: on-line type UPS and switched-type UPS. It occurred that the switched-type UPS failed to respond under voltage-dip simulations. The supply to the computer and server could be affected during voltage dips and cause the computer and server to hang up. Manual reset was required.

Investigation and Finding
A switched-type UPS was identified as the problem. Simulation tests revealed that the switched-type UPS was not suitable for sensitive equipment. The change-over time (from standby to battery discharge mode) of switched-type UPS depends on the severity of the voltage dip. Under some marginal conditions, the change-over time may be longer and affect the operation of the sensitive loads.
Conclusion and Recommendation
The switched-type UPS should be replaced by a true on-line type UPS for protection of sensitive equipment against voltage dips.

Planning Ahead Tips
- UPS sensitivity level and mode of operation, i.e., switched-type or true on-line type.
9. Uninterruptible Power Supply and Automatic Transfer Switch

Problem Area
Customer advised that their Residual Current Device (RCD) tripped when UPS ran at battery mode (discharging) and UPS out-of-sync alarm came up occasionally.

Another customer advised that their UPS discharged and ATS (automatic transfer switch) operated too frequently. Occasionally, some sensitive equipment was found tripped even though UPS was provided.

Investigation and Finding
Measurements revealed that the harmonics of some major circuits were very high. High harmonics caused tripping of RCD. Sometimes, UPS might also trip on out-of-sync.

Investigation also revealed that the rated input voltage of the UPS was 240V which was higher than the actual rated voltage value. Switched-type UPS was also used. The voltage sensitivity of the UPS was set too high.
Conclusion and Recommendation

- It is recommended to add a harmonic-suppression filter or equivalent device. Harmonic-immune RCD should be considered alternatively.
- UPS/ATS voltage sensitivity set too high and caused UPS to switch to battery mode or ATS to operate on minor voltage variations and shorten equipment life.
- Switched-type UPS was used and it responded too slowly under marginal voltage fluctuation condition. It is recommended to use true on-line UPS.

Planning Ahead Tips

- UPS voltage rating, sensitivity level and mode of operation, i.e., switched-type or true on-line type.
10. Capacitor Bank

Problem Area
Capacitor banks/units are commonly employed for power-factor correction. Customer advised that some capacitor banks frequently blew out. The temperature of the main neutral conductor was found to be too high. Computerized and telecommunications equipment was found to have failed occasionally.

Switching mode power supplies, variable speed drives and other power electronics could generate different level of harmonics in the network. Harmonics are disturbances which can cause capacitor bank and neutral cable overload. They can also affect or even damage sensitive equipment.

Investigation and Finding
Measurements revealed that the harmonics of the building were too high.
**Conclusion and Recommendation**

It is recommended to install harmonic-suppression filters. For new installations, baseline measurements should be taken. Periodic review of the harmonic content should be carried out in order to mitigate the problem caused by excessive harmonics.

**Planning Ahead Tips**

- Estimate harmonic level of all related circuits.
- Harmonics of future equipment added / installed by tenants.
- Application of active harmonic filter.
11. Earth Leakage Protection and RCD

Problem Area
Some residual current devices (RCD) of certain circuits in commercial offices could trip occasionally. CLP Power carried out an investigation and found that harmonics and current transients produced by a large number of computers was the major cause of RCD tripping.

Investigation and Finding
Harmonics are disturbances which may be generated by power electronics and non-linear loads (electronic devices, computers and printers). They can also affect the performance of precision machinery or even cause damage to some sensitive electronics. For installations with high harmonics, there is a technical limitation to the application of RCD on computers and peripherals. In general, one RCD can provide stable protection for a few computers only (say 3 to 6 sets, depending on loading). Grouping too many computers (or
electronics devices) on one RCD alone reduces the stability of the device. The chance of malfunction then increases.

Conclusion and Recommendation

- High harmonic content could be a major cause of RCD tripping. The addition of a harmonic-suppression filter is suggested.
- The cumulative trace capacitance of electronic device/computer loads could introduce transient leakage current under voltage-dip conditions and thus trigger the operation of the RCD.
- It is recommended to consult an electrical contractor on adding a new RCD, and checking the insulation and current leakage on individual devices.
- Harmonic-immune RCDs are available on the market which can provide leakage protection for circuits with high harmonics.

Planning Ahead Tips

- Estimated harmonic level of all related circuits.
- Harmonics of future equipment added/installed by tenants.
- Application of active harmonic filter.
High-speed production lines and computer-controlled machines are very sensitive to voltage dips. Moreover, some of them may generate harmonics. These may result in operation disruption, loss of critical facilities or even damage to equipment.

1. Computerized Control Machine
Problem Area
A customer advised that their high-speed computer-controlled machine malfunctioned occasionally. During routine maintenance, some power-factor improvement capacitors were also found to have failed.

Under voltage dips, the machine concerned tripped and resulted in production disruption.

Investigation and Finding
Measurements revealed that the harmonics of some major circuits were very high. High harmonics caused significant errors in the machine signal bus. Moreover, the high harmonic current overloaded the capacitor bank, hence shortening the service life of the capacitor units.

To prevent voltage dips causing machine-tripping, a simulation test was conducted in order to identify the weak link in the machine. Based on test results, the first weak link was identified. To counter voltage dip, an uninterruptible power supply (UPS) unit was added to the computer control circuit and programmable logic controller (PLC). Thereupon, further voltage-dip simulations followed. To everyone’s surprise the machine still tripped, even with a very short 50ms voltage dip. Further investigation revealed that tripping was triggered by another weak link, namely the machine pressure sensor. Since the second weak link was not as sensitive as the first one, it could only be identified after rectifying the first.
Conclusion and Recommendation

- For the harmonic problem, it is recommended to add a harmonic-suppression filter or equivalent device.
- For the voltage dip problem, a UPS should be added to secure the supply to the control circuits.
- Pressure sensor should also be modified to provide stable output status during voltage dips.

Planning Ahead Tip

- Estimate harmonic level of all related circuits.
- Harmonics of future equipment/machine added.
- Application of active harmonic filter, on-line UPS and sensor sensitivity and stability.

2. Variable Speed Drive

Problem Area

A chemical manufacturer was experiencing tripping on one or more machines on its production line. As a stoppage anywhere along the line brings the whole production process to a halt, tripping of even one single machine was...
causing significant losses to the company. Tripping occurred during voltage dips and overall restoration time to get the production line back to normal was as long as one or two hours.

Investigation and Finding
It was soon established that most of the machines used on the production line were motor-driven and controlled by Variable Speed Drive (VSD). It was discovered that the machine had an ON/OFF control contactor and a Variable Frequency Controller (VFC). Through testing and examination, it was found that the control contactor dropped off during a voltage dip. The VSD was also found to be equipped with an auto-restart option designed to re-start the machine after a short power failure. However, default setting of the auto-restart was set at ‘Inactive’.

Conclusion and Recommendation
- It is recommended to by-pass the control contactor and also modify the VSD to take up the ON/OFF control function.
- The VSD voltage dip/power loss auto-restart function should be activated in this case. To be more reliable, ride-through device should be used.
- These requirements have been incorporated in the purchasing specifications for new machines.

Planning Ahead Tips
- Control contactor drop-off.
- VSD voltage dip ride-through setting, voltage dip / power loss auto-restart setting.
- Specification for new machines.
Equipment mal-operate

Due to supply problem?

Yes: Seek help from Equipment supplier

No: Supply restored?

Yes: Can Equipment be restored and work normally?

No: Is supply from Utility normal?

Yes: PQ investigation:
Identify affected equipment. e.g. ACB, distribution board, RCD, changeover scheme, ATS of UPS, Chiller, building automation, HID lamp, lift, escalator, computer, computer control machine and variable speed drive etc.

Evaluate possible solution using Problem Solving and Planning Ahead Table P.44 - P.51

Take appropriate solution (Device or Method)

PQ problem solved?

No: Seek professional assistance

Yes: End
Appliance Symptom Recommendation

**Air-conditioners**

- **Symptom:** Original design did not cater to load growth and use of high-demand appliances, like air-conditioner.
- **Symptom:** Customer’s main building ACB tripped after voltage dip as a result of over-current protection activated due to excessive restart current surge.

**Recommendation:**

- The tripping of ACB could be attributable to the high load demand under hot weather and sudden load fluctuation during voltage-dip incidents.

**For high-rise buildings:**

- Supply upgrading or load diversion is proposed in order to reserve more capacity for sudden load demand and current fluctuation.
- Extremely inverse-type over-current protection relays can allow more time margin for riding through the re-start current of the A/C compressor motor without sacrificing the reliability of the protection.
- Thorough load growth estimation and close monitoring of load demand would be necessary.

**For schools:**

- Installation of 3-minute auto re-start control box is proposed to offer additional features for the contactor for grouped control of air-conditioners. The control box will cause the contactors of all air-conditioner groups to drop off on voltage dip and switch them in again in sequence after a 3-minute delay.
- Supply upgrading or load diversion to allow more margin for current surge.

---

**Planning Ahead Tips**

- Reserved capacity for load fluctuation.
- Air-conditioner or large machine starting current under normal and voltage-dip conditions.
- Air-conditioner with instant compressor cut-off on voltage dip and automatic time delayed reset.

---

<table>
<thead>
<tr>
<th>Equipment on Your Premises</th>
<th>Appliance</th>
<th>Symptom</th>
<th>Recommendation</th>
</tr>
</thead>
</table>
| Air-conditioners (mainly for window type) | • Original design did not cater to load growth and use of high-demand appliances, like air-conditioner. | The tripping of ACB could be attributable to the high load demand under hot weather and sudden load fluctuation during voltage-dip incidents. | **For high-rise buildings:**

- Supply upgrading or load diversion is proposed in order to reserve more capacity for sudden load demand and current fluctuation.
- Extremely inverse-type over-current protection relays can allow more time margin for riding through the re-start current of the A/C compressor motor without sacrificing the reliability of the protection.
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<th>Symptom</th>
<th>Recommendation</th>
</tr>
</thead>
</table>
| Chiller Plant | Tripped during voltage dip incident          | • Allowing the chiller to ride through the voltage dip and introducing auto re-start control to the chiller are two common tactics for reducing the impact of voltage dip on the chiller plant. Effective solutions are to provide on-line UPS for the chiller controls and apply new software with auto re-start control option.  
• Chiller plants are sometimes wired into the building automation system. Such systems sometimes provide a customized control sequence for automatically re-starting the chiller plant equipment during voltage-dip incidents. Modification of the software in the building-automation system can provide a new switching sequence to achieve this target under the routine scheduling program.  
• A centralized control panel is another typical feature of a chiller plant. By securing its control supply through a power-quality improvement device, e.g., UPS or dip-proofing inverter, constant running of the chiller plant can be maintained.  
• Some chillers may have stringent requirements that do not permit voltage dip ride-through. They therefore trip instantly during a voltage dip. However, improving the ride-through capability of the chilled water pump can maintain the flow of cold water throughout the building. This can help to maintain the desired temperature of the building while the chiller is being restarted.  
• Some chillers can cause voltage dip problem during motor starting, current limiting device should be used.                                                                 |

**Planning Ahead Tips**

1. Install reserve capacity for load fluctuation.  
2. Program for auto re-start for chiller plant.  
3. Auto-transformer starter, soft-starter or other current limiting device to prevent voltage dip caused by motor starting.
<table>
<thead>
<tr>
<th>Appliance</th>
<th>Symptom</th>
<th>Recommendation</th>
</tr>
</thead>
</table>
| Building Automation Building Management System (BMS) and Direct Digital Controller (DDC) | Centralized PC, distributed units or DDC hung up | ▪ Switched-type UPS, which had a slow response under marginal conditions, could cause distributed unit/controller to hang up due to voltage fluctuations. True on-line type UPS is recommended.  
▪ Too many status changes and alarms came up during system disturbance and caused the BMS to hang up. It is recommended to ensure/improve system performance on signal flooding.  
▪ Scheduling should include auto re-starting of chiller and chilled water pump after voltage dip. |

**Planning Ahead Tips**  
- Reliability of central PC and distributed unit under voltage dip or other disturbances.  
- Simulation of alarm flooding under system disturbance.  
- Program for auto re-start for chiller plant.  

| HID lamp (high-intensity discharge lamp) | Temporarily extinguished after voltage dip | ▪ Use ballast with better voltage dip ride-through capability.  
▪ Use double-tube lamp.  
▪ Add hot re-strike igniter (for higher power lamp).  
▪ Use energy saving fluorescent lamp (CFL - compact fluorescent lamp) or LED floodlight to replace high-pressure lamp (for lower power lamp).  
▪ Evenly distributing the lamps to three phases.  
▪ Use power-quality improvement equipment (e.g., DC battery source, UPS, dip proofing inverter). |

**Planning Ahead Tips**  
- Emergency battery back-up or UPS for underground car-park lighting.  
- Voltage dip ride-through capability of discharge lamp.
### Appliance: Lifts and Escalators

**Symptom**
- Lift - Tripped and with passenger 'shut-in-lift' during voltage-dip incident
- Escalator - Tripped during voltage-dip incident

**Recommendation**

#### For Lifts:
- If there were no hidden mechanical defects, the lift should be able to auto restart and perform 'Homing' function, which is an essential feature for fireman's lift. Inclusion of checking of auto re-start or power loss homing function in maintenance procedures should be considered.
- If the homing time is too long during re-starting, emergency floor opening in the tunnel zone could be modified to be used as landing floor for passenger evacuating. Alternatively, high-speed floor locating should be considered. Low-speed floor locating during re-start is always misinterpreted by passengers as shut-in-lift.
- If the lift tripped on stalled-motor timer when the lift is repositioning itself at low speed, sensor should be added to feedback running status to reset the timer. Alternatively, high-speed floor locating should be considered.
- Mechanical defect and damaged voltage arrestors should be cleared and replaced through effective routine maintenance.
- Effective intercom to duty guard post is desirable (instead of relaying to un-manned machine room).
- Recommend lift-status display lantern, designed to comfort passengers when the lift is tripped or is restarting at low-speed.
- Dynamic reactive compensator should be added to reduce voltage dip caused by starting current surge.
- Voltage dip immunity components should be considered to enhance the ride-through capability of the control circuits and/or motor drive.
- Post-voltage-dip operation (refer to the latest edition of COP on the Design and Construction of Lifts and Escalators) and ARD (Automatic Rescue Device) should be considered.
- Advanced type motor drive equipped with kinetic buffering and/or regenerative feature should be considered.

#### For Escalators:
- To use on-line UPS or DC battery source to secure the supplies to the control contactors and PLC.
- To replace the phase monitoring relay with a new one that equipped with a short time delay in order to allow the escalator to ride through short voltage dip.
- To modify the setting of the variable speed drive in order to enhance the ride-through capability.
- For adding ride-through feature, please refer to latest version of COP on the Design and Construction of Lift & Escalator.

### Planning Ahead Tips

- Voltage dip ride-through capability of the lift and escalator.
- Effectiveness of auto re-start or homing feature of lift under different conditions after a voltage dip.
<table>
<thead>
<tr>
<th>Appliance</th>
<th>Symptom</th>
<th>Recommendation</th>
</tr>
</thead>
</table>
| Distribution Board        | • Control scheme tripped                                                 | • The AC-driven voltage relay and the auxiliary relay of the scheme might malfunction and trip off the ACB during voltage dip. Ordinary AC timer could not provide true off-delay function.  
• It is recommended to modify the scheme to DC scheme (with battery back-up), to add coil hold-in device or on-line UPS to secure the control supply of the protection scheme. |

**Planning Ahead Tips**  
- Use of DC scheme and equipment with battery and charger.  
- True off-delay timer.

| Change-over Scheme, Back-up Gen-set, Fire and Security System | The events below happened during voltage dip incidents:  
• Normal breaker tripped off, essential breaker closed to divert the essential loads, but back-up gen-set failed to start.  
• Back-up gen-set started up for several seconds during voltage-dip incident.  
• Fire and security equipment alarms came up.  
• Supply interruption to essential facilities (e.g., lift) although supply from power utility was healthy | To employ DC supply for the change-over and other control schemes because AC-driven relays malfunctioned during voltage-dip incidents. This is similar to most fire and security systems that employ DC with battery back-up as control supply to enhance scheme reliability.  
• To employ coil hold-in device to reduce the chance of relay chattering under voltage-dip conditions.  
• To employ true off-delay relay to work in coordination with the under-voltage relay in order to allow short delay before issuing trip signal to the respective breaker under voltage-dip conditions, or start command to back-up gen-set.  
• It would be desirable to adjust the voltage setting of the scheme in order to allow sufficient margin for ignoring transient disturbances, which may be produced by starting of heavy machinery or sudden load changes at load side. The operating time setting should be long enough to ride-through most voltage-dip conditions in order to achieve higher reliability. |

**Planning Ahead Tips**  
- Reliability of the scheme under voltage dip.  
- Use of DC scheme and equipment with battery and charger.  
- True off-delay timer.  
- Over- / under-voltage and time-delay setting of change-over scheme.
<table>
<thead>
<tr>
<th>Appliance</th>
<th>Symptom</th>
<th>Recommendation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Computers and Servers</td>
<td>Reset, rebooted or hung after voltage dip</td>
<td>• It is also recommended to adopt appropriate UPS output setting and consider using on-line type UPS for sensitive equipment.</td>
</tr>
<tr>
<td><strong>Planning Ahead Tips</strong></td>
<td></td>
<td><strong>UPS sensitivity level and mode of operation, i.e., switched-type or true on-line type.</strong></td>
</tr>
</tbody>
</table>
| Uninterruptible Power Supply (UPS) and Automatic Transfer Switch (ATS) | ▪ RCD tripped when UPS ran at battery mode (discharging) and UPS out-of-sync alarm came up.  
▪ UPS discharged or ATS (automatic transfer switch) operated too frequently.  
▪ Sensitive equipment tripped even when UPS was provided.                                    | ▪ High harmonics caused tripping of RCD, and UPS might also be tripped on out-of-sync. It is recommended to add harmonic-suppression filter or equivalent device. Alternatively, a harmonic-immune RCD should be considered.  
▪ UPS/ATS voltage sensitivity set too high and caused UPS to switch to battery mode or ATS to operate on minor voltage variations and shorten equipment life. The sensitivity level of the UPS should be properly adjusted.  
▪ Switched-type UPS was used and it responded too slowly under marginal voltage fluctuation conditions. It is recommended to use true on-line UPS. |
| **Planning Ahead Tips**                            |                                                                                                                                 | **UPS voltage rating, sensitivity level and mode of operation, i.e., switched-type or true on-line type.**                                    |
| Capacitor Bank                                     | ▪ Capacitor bank blown out frequently.  
▪ Neutral conductor high temperature.  
▪ Computerized equipment failure.  
▪ Telecommunications equipment failure                                                   | ▪ Harmonics of the building too high.  
▪ Add harmonic-suppression filter.  
▪ Baseline measurement and periodic review of harmonic level would be desirable.            |
| **Planning Ahead Tips**                            |                                                                                                                                 | **Estimate harmonic level of all related circuits.**  
**Harmonics of future equipment to be added / installed by tenants.**  
**Application of active harmonic filter.**                                                   |
### Appliance Symptom Recommendation

<table>
<thead>
<tr>
<th>Appliance</th>
<th>Symptom</th>
<th>Recommendation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Earth Leakage Protection and RCD</td>
<td>Tripped occasionally after voltage dip</td>
<td>• When high harmonic content could be a major cause of RCD tripping, the addition of a harmonic-suppression filter is suggested.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• The cumulative trace capacitance of the electronic devices/computer loads could introduce transient leakage current under voltage-dip conditions and thus trigger the operation of the RCD.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• It is recommended to consult an electrical contractor on adding new RCD, checking the insulation and leakage current of individual devices.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Harmonic-immune RCDs are available on the market; they can provide leakage protection for circuits with high harmonics.</td>
</tr>
</tbody>
</table>

**Planning Ahead Tips**
- Estimate harmonic level of all related circuits.
- Harmonics of future equipment to be added / installed by tenants.
- Application of active harmonic filter.
### Production Lines and Machines

<table>
<thead>
<tr>
<th>Appliance</th>
<th>Symptom</th>
<th>Recommendation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Computerized Control</td>
<td>▪ Machine malfunctioned occasionally</td>
<td>▪ For the harmonic problem, it is recommended to add a harmonic-suppression filter or equivalent device.</td>
</tr>
<tr>
<td>Machine</td>
<td>▪ Power factor improvement capacitor failed</td>
<td>▪ For the voltage-dip problem, UPS was added to secure the supply for the control circuits.</td>
</tr>
<tr>
<td></td>
<td>▪ Machine tripping under voltage dip</td>
<td>▪ Pressure sensor was also modified to provide stable output status under voltage dip.</td>
</tr>
<tr>
<td><strong>Planning Ahead Tips</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>① Estimate harmonic level of all related circuits.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>② Harmonics of future equipment/machine added.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>③ Application of active harmonic filter, on-line UPS and sensor sensitivity and stability</td>
<td></td>
</tr>
<tr>
<td>Variable Speed Drive</td>
<td>▪ Control contactor dropped off</td>
<td>▪ It is recommended to by-pass the control contactor and also modify the VSD to take up the ON/OFF control function.</td>
</tr>
<tr>
<td></td>
<td>▪ Variable speed drive tripped under voltage dip</td>
<td>▪ The VSD voltage dip/power loss auto-restart function should be activated in this case. To be more reliable, ride-through device should be used</td>
</tr>
<tr>
<td></td>
<td></td>
<td>▪ These requirements have been incorporated into purchasing specifications for new machines.</td>
</tr>
<tr>
<td><strong>Planning Ahead Tips</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>① Control contactor drop-off.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>② VSD voltage dip ride-through setting, voltage dip / power loss auto re-start setting.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>③ Specification for new machine.</td>
<td></td>
</tr>
</tbody>
</table>
Appendices

Appendix 1 - Illustration of Equipment Voltage Dip Susceptibility
International Electrotechnical Commission -
IEC 61000-4-34 / 61000-4-11

Equipment should be able to
ride through in this region

40%, 0.2s

70%, 0.5s

Voltage (percent of Nominal)

Duration of Disturbance (seconds)
Appendix 2 - Extract from CLP Power’s Supply Rules Section 220 on harmonics and other operational limits of customer’s equipment.

<table>
<thead>
<tr>
<th>Type of Distortion</th>
<th>Type of Abnormal Load</th>
<th>Operational Limit</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Voltage Fluctuation</strong></td>
<td>Electric arc furnace</td>
<td>For 132kV and below 2%</td>
</tr>
</tbody>
</table>
|                     | Motor starting | • Infrequent intervals exceeding 2 hours 3%  
|                     |               | • Frequent intervals not exceeding 2 hours 1% |
|                     | Rolling mill and traction (motor starting intervals not exceeding several minutes) | • Step-type change:  
|                     |               | up to 66kV 1%  
|                     |               | 132kV 0.75%  
|                     |               | • Ramp-type change:  
|                     |               | up to 66kV 1%/sec  
|                     |               | 132kV 0.75%/sec  
|                     |               | • Limit of total change:  
|                     |               | up to 66kV 3%  
|                     |               | 132kV 2.25%  
| **Voltage Unbalance** | Single phase electric traction load | Voltage:  
|                     |               | negative sequence 2% of positive sequence  
|                     |               | Current into generators:  
|                     |               | negative sequence 5% of positive sequence  
| **Harmonic Voltage Distortion** | Electric arc furnace | • At 132kV or above  
|                     |               | odd harmonic distortion 1%  
|                     |               | total harmonic distortion 1.5%  
|                     |               | • At 66kV or 33kV  
|                     |               | odd harmonic distortion 2%  
|                     |               | total harmonic distortion 3%  
|                     |               | • At 11kV  
|                     |               | odd harmonic distortion 3%  
|                     |               | total harmonic distortion 4%  
| **Harmonic Current Distortion** | Other Non-linear Equipment with size “I” in Ampere | • At 380V/220V  
|                     |               | total odd harmonic distortion  
|                     |               | \( I < 30A \) 20%  
|                     |               | \( 30A \leq I < 300A \) 15%  
|                     |               | \( 300A \leq I < 600A \) 12%  
|                     |               | \( 600A \leq I < 1500A \) 8%  
|                     |               | \( I \geq 1500A \) 5%  
|                     |               | total even harmonic distortion:  
|                     |               | 25% of the odd harmonic limits  


CLP Power is committed to maintaining and delivering a reliable supply of electricity. We are always pleased to provide further information on Power Quality to customers. If you have any enquiry on Power Quality, please contact our customer telephone services officers at 2678-2678 (CLP INFO-LINE).