Mitigation of Power Quality Issues (Transients & Neutral to Ground Voltage) Using Ultra Isolation Transformer
Abstract:
An engineering company in western India opted to address power quality issues in the green field project. For a heavy engineering company engaged in manufacturing of turbine power quality becomes very important as the raw material is very costly. Apart from using costly raw material the process is very critical and time consuming. In critical engineering processes where quality and reliability is very important, any breakdown during the process could result in huge losses. The losses could be in terms of wastage in raw material, time and energy spent during the process.

The facility uses sophisticated CNC machines those can tolerate a maximum of 200mV to 300mV neutral to ground voltage. The machine gives alarm or do not work if neutral to ground voltage increases beyond this value. Absence of transients or noise in electrical supply is other critical need for CNC machine for its operation.

The industry opted to use ultra-isolation transformer in the green field project to address following power quality issues.

1. Transients
2. Neutral to ground voltage
3. Minimum neutral current
4. Harmonics

A measurement based study was carried out to find benefits associated with the ultra-isolation transformer.
Introduction

With the increased use of digital control, power quality is a phenomenon that Industries had to live with. Power electronics is helping industries with better ways for control and automation, enhanced quality, improved productivity and lesser energy consumption. In order to get all above benefits, it is very important to ensure that best quality of power is supplied to all these machines and equipment. These electronic devices are susceptible to any deviation in quality of power that is supplied. Apart from being susceptible to any deviation in power quality, it is worthwhile to note that these devices also cause power quality problems. These are the issues that cannot be ignored and industry has to find solutions for:

1. Supply of electrical power free from any aspect of power quality challenges
2. Mitigate the power quality issues generated by these devices to ensure reliability of other equipment.

The case study depicts some of the power quality parameters in details that are mitigated by a manufacturing industry using an isolation transformer.

Addressed Power Quality Issues:

Harmonics:

Harmonics are one of the most common and widely discussed subjects in power quality. Harmonics are integer multiple of fundamental frequency wave form. Harmonic currents are produced by non-linear loads and higher level of harmonics can generate voltage distortion. Harmonics can be classified in to following three categories.

1. Positive Sequence Harmonics

Harmonic current which rotate with fundamental current are called positive sequence harmonics. 1st, 7th, 13th, and 19th are example of positive sequence harmonics. The sequence produces magnetic fields and currents rotating in the same direction as the fundamental frequency harmonic. In an induction motor, positive sequence harmonics tend to push the rotor in the same direction as of fundamental waveform. Interaction of positive and negative sequence of harmonics can create vibrations in the rotor of the motor.

2. Negative Sequence Harmonics

Harmonics current which rotate in opposite direction are called negative sequence harmonics. 5th, 11th, 17th and 23rd are examples of negative sequence harmonics. As direction
of rotation of these harmonics is opposite to that of fundamental waveform, they tend to push the rotor in opposite direction i.e. like stalling effect. In an atmosphere where 5\textsuperscript{th} harmonics are predominant, motors are de-rated and tend to overheat.

3. Zero Sequence Harmonics

Harmonic whose phasor is not displaced are called Zero sequence harmonics. These are also known as triplen harmonics. All integer multiple of three (3) and odd order are triplen harmonics. 3\textsuperscript{rd}, 9\textsuperscript{th}, 15\textsuperscript{th} and 21\textsuperscript{st} orders are example of triplen harmonics. Unlike positive and negative sequence harmonics, which propagate in the upstream of the network, triplen harmonics do not propagate in to the higher voltage levels of the distribution system. They are restricted to the lower voltage level i.e. secondary side of the distribution system.

These are generated by SMPS loads and as the case study deals with triplen harmonics, these shall be discussed in detail.

**Significant levels of triplen harmonics in a low voltage, three phase, four wire system will have a severe impact on both the power distribution system and the devices connected to it. Triplen currents may include any or all of the following symptoms:**

- High Neutral Current
- High Neutral to Ground Voltage (Common Mode Noise)
- High Peak Phase Current
- High Average Phase Current
- High Total Harmonic Distortion of the Current
- High Total Harmonic Distortion of the Voltage
- High Transformer Losses
- High System Losses
- Apparatus Overheating
- Low Power Factor
- Electronic Protective Device Malfunction
- High Telephone Interference Factor
- Increased Apparatus Vibration

Ironically, the devices which create the third order, zero sequence harmonics may be the most sensitive to the problems they create. The performance of the switch mode power supply, in particular the charging of its capacitor, is critically dependent on the magnitude of
the peak voltage. These voltage harmonics can cause "flat topping" of the voltage waveform or lowering of the peak voltage. In severe cases the control modules may reset due to its own power supply's failure.

**Transients:**

As per ANSI std. 1100-1992 transients are defined as “a sub-cycle disturbance in the AC waveform that is evidenced by a sharp brief discontinuity of the waveform. Transients may be of either polarity and may be of additive or subtractive energy to the nominal waveform”. Transients can be divided in two categories

1. **Impulsive Transients**

Impulsive transients are low frequency that rises in 0.1 micro seconds and can lasts more than 1 mili second. It is defined by IEEE 1159 as a sudden, non–power frequency change in the steady-state condition of voltage, current, or both that is unidirectional in polarity – either primarily positive or negative. It is normally a single, very high impulse like lightning.

![Impulsive Transient](image)

**Fig – 1 Impulsive transient**

Figure 1 shows an example of impulsive transient. Impulsive transients are generally described by the rise and decay time of the transient. For example a 1.5 x 45 micro second 1500 V impulse transient rises from zero to its peak of 1500 volts in 1.5 micro second and decays to half of its maximum value in 45 micro seconds.

Lightening is one of the major causes of impulse transients. A lighting strike can generate current as high as several thousand amperes in 2-3 micro seconds. In addition to this, this sudden rise in current also has frequencies in the range of MHz.
Electrostatic discharge is one of the reasons for generation of impulsive transients. Although electrostatic discharge is not as high in amplitude as lighting, but if generated in the electronic machine, sudden release of charge that is developed due to electrostatic can damage electronic equipment.

2. **Oscillatory Transients:**

Oscillatory Transient is described as a sudden; non-power frequency change in the steady-state condition of voltage, current, or both that has both positive and negative polarity values (bidirectional).

Unlike impulse transients, Oscillatory transients are low frequency transients up to 5 kHz and are more common in low voltage power system. These transients can propagate in the power system and have a tendency to be amplified due to resonance phenomenon of other equipment in the power system.

Depending on the frequencies, these transients can be further classified as below.

**Low-frequency oscillatory transient**

These are one of the most common type of transients that occur in a distribution system. Main cause of origination of these transients is energisation of capacitor banks. Now a day, capacitor banks are present in all electrical distribution system to achieve unity power factor. In order to maintain unity power factor, capacitor banks are switched on and off to match varying inductive load. Each time a capacitor bank or a capacitor is switched on, capacitor bank energisation takes place. Energisation of capacitor bank yields an oscillatory voltage transient with frequencies between 250 and 750 Hz. Theoretically, its magnitude can go as high as twice the system voltage but system damping typically limits the values from 1.3 to 1.5 times of system voltage, with a duration of 1/2 to 3 cycles.

Also, oscillatory transients with fundamental frequencies less than 250 Hz can be observed on the distribution system due to transformer energisation and ferro-resonance. In addition, series capacitors may also produce this transient type when the system resonance causes the magnification of low-frequency components in the transformer inrush current or when unusual conditions lead to ferro-resonance.
Medium-frequency oscillatory transient
An example of this transient type is the back-to-back capacitor switching. It occurs when a capacitor bank is switch in close electrical proximity to another capacitor bank that is already energized, which sees the de-energized bank as a low impedance path. Figure 2 shows an example of oscillatory transient due to back to back capacitor switching.

![Oscillatory Transient Due to Back-to-Back Capacitor Switching](image)

Other causes of medium-frequency oscillatory transient include cable switching and as a system response to an impulsive transient.

High-frequency oscillatory transient
These transients are linked with power electronics and switching events (e.g. line or cable energization). Power electronics, like the switching power supply in computers, generate oscillatory voltage transients that repeat several times the fundamental frequency (50 Hz) cycle. Usually, they are also the result of a local system response to an impulsive transient.

Above mentioned two categories of transients (Impulse and Oscillatory) can be classified as differential mode transients and common mode transients.

Differential Mode Transients:
If the transients are induced on a line with reference to neutral, they are known as differential mode transients. In this mode, voltage on one of the line is elevated. These are
generated by internal events like switching of loads. Figure 3 shows a differential mode transient where voltage in a phase is elevated.

**Common Mode Transients:**
In common mode transients, voltage on all the phases is elevated. These are generated through external sources like lightning. Figure 4 shows an example where voltage is elevated in all phases with reference to ground.

![Fig –3 Differential Mode Transients](image)

![Fig - 4 Common Mode Transients](image)

**Neutral to Ground (N-G) Voltage:**
One of the adverse effects of transients is elevated N-G voltage which may not be acceptable to some critical equipment. Some equipment installation specifications list extremely small values for acceptable N-G voltage, such as 0.2V to 0.3V. It becomes quite difficult to meet these stringent requirements to maintain so low N-G voltages and there have been cases where people were trying to reduce ground resistance below possible limits.

Common mode transients can cause N-G voltage rise. Figure - 5 below shows measurements carried out to demonstrate effect of common mode transients on N-G voltage rise.

![Fig –5 Common Mode Transients causing rise to NG voltage](image)
In the system, ground reference potential was common to both current carrying conductor and only return path to any interference is through the reference ground potential. In the figure, voltage wave form is close to a sinusoidal without presence of any harmonics. However there are common mode transients present in the system. Whenever there is an event of common mode transients, there is increase in N-G voltage as indicated by blue waveform. Rise in N-G voltage as depicted in above waveform can seriously damage the electronic circuit in the system and the communication ports.

**Facility Description:**

L&T MHI TURBINE GENERATORS Private Limited is a flagship company of the Engineering & Construction Division of Larsen & Toubro Limited. Larsen & Toubro Limited (“L&T”) and Mitsubishi Heavy Industries Limited (“MHI”) have inked a Joint Venture Agreement for setting up a manufacturing facility to supply Environment friendly super-critical Steam Turbine & Generator facility in Hazira. This follows a Technology Licensing and Technical Assistance Agreement for manufacture of super-critical Turbine & Generator, signed between L&T MHI, and Mitsubishi Electric Corporation (Mitsubishi Electric). The product, an integral component of energy efficient coal based power plants, is expected to meet the demand / supply gap for power plant equipment as envisaged in the country’s plan for a mega ramp up in power generation capacity using super-critical technology. In order to manufacture these super critical turbines, upmost quality with zero tolerance has to be maintained for even the smallest component. The Machines used are very high accuracy CNC machines with multiple axis systems. For any machining operation, an accuracy range of 10 microns needs to be maintained. In order to maintain this level of accuracy, power supply without any disturbances and deviations and as per international norms has to be fed to these machines. Apart from this, the machining operation for the components can go up to hours and any interruption or deviation in the power supply can cause rejection of the component causing economic loss.

LMTG considered power quality issues during the design stage and opted to take mitigation measures to protect the machines against any kind of failure. In order to protect the machines from any kind of failure, achieve quality of product and reliability of operation LMTG has opted to install Ultra Isolation Transformer to address power quality issues. At the plant, all CNC machines are supplied as per below schematic diagram (Fig – 6).
Measurements:

In order to evaluate benefits associated with the isolation transformer measurements were carried out at the input of voltage regulator and output of isolation transformer for harmonics and transients. The measurements were carried out using two numbers of power analyser Fluke – 435 which is in compliance with EN50160 standard. Figure – 7 shows one of the meters installed at the site and figure 8 shows connection at isolation transformer.

Measurements were carried out for harmonics, neutral to ground voltage and transients. Details of the measurement and analysis for the same are shown below.

Harmonics:

Measurements were carried out at the input to voltage regulator and output of isolation transformer simultaneously. Graphs below show variation in the harmonic percentage of at the input of voltage regulator and output of isolation transformer.
Graph -1 shows total harmonic distortion in terms of percentage for all phases including neutral. From the graph it can be seen that for the phases R, Y and B, total average current harmonic distortion is 4.07%, 4.13% and 4.78% respectively. At the output of isolation transformer average value of total current harmonic distortion is 4.47%, 5.13% and 4.91% respectively for R, Y and B phase. There is not much change is harmonic distortion level at the input and output of the isolation transformer.

However from the graph below it can be seen that total harmonic distortion has increased to average value of 44.6% from average value of 11.8%. In order to understand sudden rise in THD% at the output of isolation transformer, analysis of neutral current was carried out in detail.

In order to understand increase in harmonic distortion at the output of isolation transformer, change in neutral current at the input of the voltage regulator and output of isolation transformer were measured.

Graph-2 shows profile of neutral current in Amperes at the input and output of isolation transformer. From the graph below it can be seen that at the input of voltage regulator neutral current was in between 2 and 3 Amperes. Average value of neutral current at the input of voltage regulator was 2.09 amperes however at the output of the isolation
transformer; neutral current is reduced to 0.2 to 0.3 amperes with average value of 0.24 amperes.

THD % is always indicated as a percentage of fundamental RMS value of current flowing in the system. Average current flowing in the neutral of output of isolation transformer is reduced to 0.24 amperes as compared to neutral current value of 2.09 amperes at the input of voltage regulator. Along with reduction in average RMS value of current in neutral, RMS value of total harmonic distortion current is also reduced as shown in graph -3.
At the input of voltage regulator, average RMS value of total harmonic distortion current flowing in the neutral is 0.25 Amperes whereas RMS value of current flowing in the neutral at the output of isolation transformer is 0.10 amperes. However with respect to current of 0.24 amperes flowing in the neutral at the output of isolation transformer, 0.1 amperes is 43.8%. Hence it appears that total harmonic distortion at the output of the isolation transformer is very high but actually it is less as compared to input of voltage regulator.

Graph – 4 shows RMS value of individual order of harmonics. In the graph harmonics of the order of 3rd, 5th and 7th are shown. From the graph below it can be seen that at the output of isolation transformer 3rd order harmonics are less as compared to harmonics present at the input of voltage regulator. However RMS value of 5th and 7th order of harmonics is increased from the value of input of voltage regulator. Average RMS value of 3rd, 5th and 7th order of harmonics before the voltage regulator was 0.17A, 0.08A and 0.04A respectively. At the output of isolation transformer average RMS value of 3rd, 5th and 7th order of harmonics were 0.05A, 0.13A and 0.08A respectively.

![Graph-4 RMS value of harmonic](image)

From the above graph it can be seen that the isolation transformer is not allowing triplen harmonics from the system to be injected in the machine. However other orders of harmonics are found to be on higher side. This could be due to harmonics generated by the load itself.

From the above analysis it can be seen that isolation transformer is not allowing triplen harmonics from the system to be injected in the load.
Neutral-Ground Voltage:

Graph-5 shows neutral to ground voltage before and after isolation transformer. From the graph it can be seen that there is lot of variation in N-G voltage. The voltage variation at the input of voltage regulator is from a minimum value of 0.31 volts to maximum voltage level of 1.29 volts. Specified limit for the neutral to ground voltage is 200mV – 300mV but at the input of voltage regulator even the minimum voltage is above the required limit.

![Neutral - Ground Voltage](image)

Graph-5 Neutral to ground voltage

However from the graph it can be seen that at the output of isolation transformer neutral to ground voltage is constant and it is 0.06 volt (60mV) which is well under specified limit.

By installing isolation transformer, LMTG has got benefit in terms of creating a constant and very low neutral to ground voltage of 60mV.

Transients:

Measurements were carried out to study presence of transients at the input of voltage regulator and output of isolation transformer.

Input of voltage regulator:

At the input of the voltage regulator, it was found that transients were present in phases as well as in neutral. Snapshots 1-1 to 1-3 show transient present in voltage, current and neutral at the input of the voltage regulator. Although amplitude of these transients was not very high, frequency of occurrence were quite high. In a span of around 2 minutes, 12
transients were recorded. For sensitive equipment like CNC machines, even these values can cause considerable damage.

From the voltage transient snapshot 1-1, it can be seen that there are two transients present in the half waveform. These transients are highlighted in the graph below. Value of these transients is 60V.

From the snapshot **Snap shot 1-1 Voltage Transient** transients are reflected in terms of current transients. Amplitude of these transients is 103A and -135A where as RMS value of current was 60 A. These transients could cause damage to the electronic cards or digital circuits of the machine.

**Snap shot 1-2 Transient in current**

Snapshot 1-3 shows presence of voltage transient at the neutral at the input of voltage regulator. For voltage level of 1.8 volts, transient recorded in the below snapshot is of 41.2 volts. Occurrences
of these transients can cause failure of critical component in the CNC machine.

Output of isolation transformer:
Measurements were carried out at the output of isolation transformer. After analysing the measurements it was found that transients were present in the phases however there were no transients found at the neutral of the isolation transformer. Snapshots 2-1 to 2-3 show transients in phase and neutral. Snapshot 2-1 shows presence of couple of voltage transients with voltage level of 145V and 256volts.

Transients in the current waveforms generated by the voltage transients are shown in the snapshot 2-2. From the snapshot it can be seen that two corresponding transients are generated in the current wave form with peak value of 105 amperes for RMS value of 60 amperes.
Case Study 35
Mitigation of Power Quality Issues (Transients & Neutral to Ground Voltage) Using Ultra Isolation Transformer

Snapshot 2-2 Transient in current

Snapshot 2-3 shows transients recorded at neutral with reference to ground. However there were no transients observed on the neutral of the output of the isolation transformer.

Snapshot 2-2 Transients in neutral

From the above snapshots, it can be seen that at the output of isolation transformer, there are no transients present with reference to ground. However in phases transients are present at the input as well as output of isolation transformer. Isolation transformer is giving protection against common mode transients; however differential mode transients are flowing through the isolation transformer.
**Conclusion:**

From the above case study it can be seen that isolation transformer is giving very good protection against rise in neutral to ground voltage. As neutral of isolation transformer is separate from system neutral, a constant and very low neutral to ground voltage of 60mV could be attained.

Isolation transformer also provided good protection against common mode noise and transients. It was observed that there were no transients present in the neutral of the output of the isolation transformer despite presence of transients at the input to voltage regulator.

Although there were no common mode transients observed at the output of isolation transformer, differential mode transients were present. These transients can be easily filtered out using a surge protection device (SPD).

Isolation transformer did not allow flow of zero sequence harmonics from the system neutral to the machine. However there was not much change in the other order of harmonics and total harmonic distortion. There was no change in total current harmonic distortion at the output of isolation transformer.

With due precautionary measures adopted right at green field stage the sophisticated engineering unit could avoid machine breakdown, material loss and process loss triggered by various power quality phenomenon commonly plaguing industries using digitally controlled machines.
About the Author:

Author Name: Naveen Kumar Basva

Email: naveen.basva@lntpower.com

Mr Basva holds Bachelor degree in Electrical and Electronics and Post Graduate Diploma in Project Management (from IIM-Indore- L&T IPM). He is Certified ENERGY MANAGER by BEE- (Bureau of Energy Efficiency). Undertaken Advance Certificate course in Power Distribution Management (ACPDM) from IGNOU.

With total experience of 8.5 years diversified in distribution of power, EPC (Power Plant Erection and Commissioning) and now in manufacturing sector as Manager - Plant Engineering & Maintenance. One of the main responsibility is to provide reliable power supply to the super critical turbine generator manufacturing facility.

Disclaimer: The sole responsibility for the content of this document lies with the authors. It does not represent the opinion of the Asia Power Quality Initiative and/or ICPCI/ICA network. APQI and ICA network are not responsible for any use that may be made of the information contained therein.