Centralized Smart Energy Saver Systems

A Product of Alphonso Energy,
An Energy Management Division of Credence Robotics
towards United Nation Sustainable Development Goal 7

"Energy Not Wasted is Energy Created

CREDENCE ROBOTICS
Machine Personified

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ABSTRACT

This paper is intended to give an overview of Centralized Smart Energy Savers and is aimed at those who have some electronics/electrical background but little or no knowledge of harmonics. The basics of harmonics are explained briefly emphasizing thee SMPS loads. Common types of harmonic sources present in industry are addressed. The potential ill-effects due to harmonics are detailed. The methods of reducing harmonics and energy consumption are discussed along with case studies.

INTRODUCTION

Power system harmonics is an area that is receiving a great deal of attention recently. This is primarily due to the fact that non-linear (or harmonic producing) loads are comprising an ever-increasing portion of the total load for a typical industrial plant. The increase in proportion of non-linear load has prompted more stringent recommendations in IEEE Std. 519 and stricter limits imposed by utilities. Incidence of harmonic related problems is low, but awareness of harmonic issues can help to increase plant power system reliability.

A typical Manufacturing Plant or any Commercial Building will have thousands of switched-mode power supplies (SMPS) on-line, 24 hours a day, 7 days a week, 365 days a year. There's the SMPS for the computers, the power supply for Lighting systems, HVAC, Variable Frequency Drives, Inverters, DC Converters, etc. All of them produces Harmonic Currents.

THE FUNDAMENTALS

Harmonics are a mathematical way of describing distortion to a voltage or current waveform. The term harmonic refers to a component of a waveform that occurs at an integer multiple of the fundamental frequency. Fourier theory tells us that any repetitive waveform can be defined in terms of summing sinusoidal waveforms which are integer multiples (or harmonics) of the fundamental frequency. Understanding the mathematics is not important. What is important is understanding that harmonics are a steady state phenomenon and repeat with every 60 Hz cycle. Harmonics should not be confused with spikes, dips, impulses, oscillations or other forms of transients. A common term that is used in relation to harmonics is THD or Total Harmonic Distortion. THD can be used to describe voltage or current distortion.

THE PROBLEM STATEMENT

"So, what's the big deal about that?" you ask. "As long as the power company can provide enough current to power the machines and we have the place wired properly so the current is distributed and the loads are balanced correctly, it's all good, right?" Well, yes and no. Sure, it all works correctly but there are hidden, insidious forces at work when you have so many switched-mode power supplies and VFDs in operation at the same time. The Harmonic Currents are dropping the efficiency of your system and likely causing you to spend thousands of extra dollars each year, not only for electric power but also for the air-conditioning required to cool your premises.

These nefarious culprits are called "harmonic currents" and High levels of harmonic distortion can cause such effects as increased transformer, capacitor, motor or generator heating, mis operation of electronic equipment (which relies on voltage zero crossing detection or is sensitive to wave shape), incorrect readings on energy meters, mis operation of protective relays, interference with telephone circuits, reduced useable system capacity, etc.

The likelihood of such ill effects occurring is greatly increased if a resonant condition occurs. Resonance occurs when a harmonic frequency produced by a non-linear load closely coincides with a power system natural frequency (50/60 Hz).

Harmonic suppression systems can be installed to eliminate the flow of the most troublesome "third harmonic" currents. Economic benefits of installing such systems include increased, Increased component lifetime and reduced electricity bills, reduced down time. Later in this discussion, you'll see how it is now possible to measure the energy savings obtained when excessive harmonic current flow is eliminated in an electrical system. These savings are due to reduced I^2R losses in transformers and wiring and reduced air conditioning costs.

Harmonic Current:

Harmonic currents are a direct result of the way in which a switched-mode power supply (SMPS) draws current from the system. The input circuit of an SMPS is a bridge rectifier that changes the 110/240-volt AC input to DC. A capacitor smoothens this DC to eliminate voltage ripples and the resultant DC bus has a voltage of about 170 volts when the AC rms input is 120 volts. Although the AC voltage is a sine wave, the rectifier draws its current in spikes as shown in *Figure 1*. These spikes require that the AC supply system provide harmonic currents, primarily 3rd, 5th and 7th. These harmonic currents do not provide power to the SMPS, but they do take up distribution system capacity.

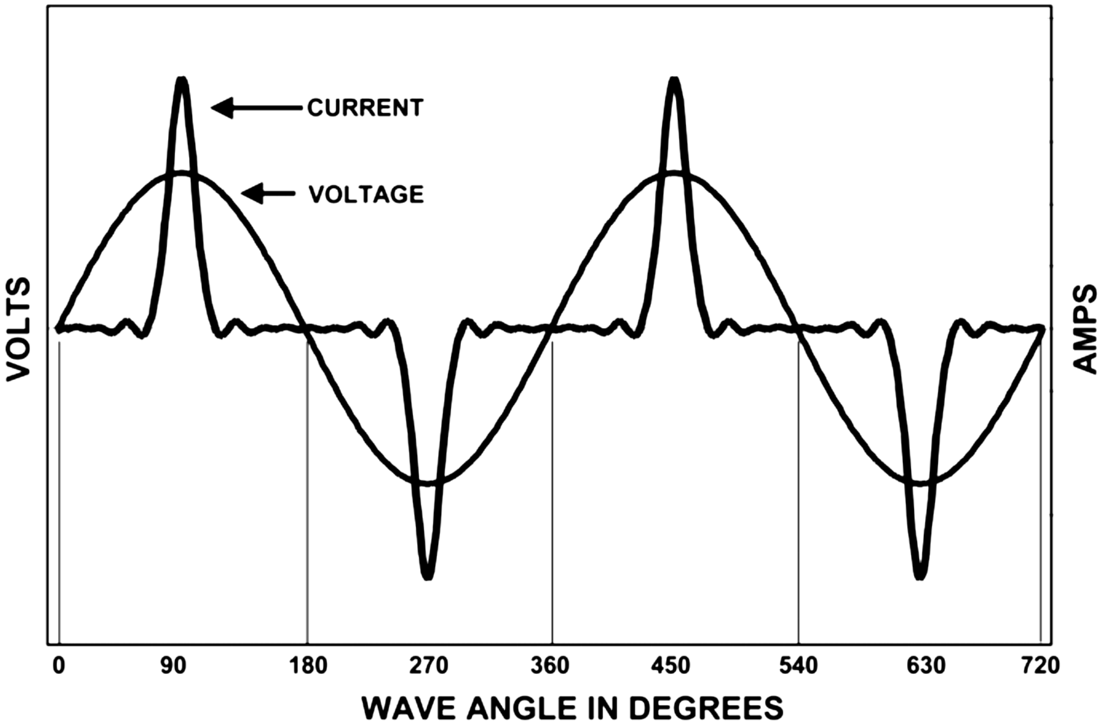


Figure 1. Here's our first problem: Although the AC voltage is a Sine wave, the Rectifier circuits in power supply systems and other circuitries draw its current in Spikes

The principal harmonic current is the 3rd (150/180 Hz) and the amplitude of this current can be equal to or even greater than that of the fundamental current.

Harmonic Current Flow in 3 Phase Systems:

When SMPS loads are connected as shown in *Figure 2*, each phase wire carries both the 60Hz fundamental current that supplies power to the SMPS and the harmonic currents that are there because of the way the SMPS draws its current. While most of the harmonic currents cancel in the neutral wire, just as the 60Hz currents do, the 3^{rd} harmonic current and other currents divisible by three are additive in the neutral wire.

Thus, if the 3rd harmonic current were 100 amps in each phase, the 3rd harmonic current returned to the X0 transformer connection by the common neutral wire would be 300 amps.

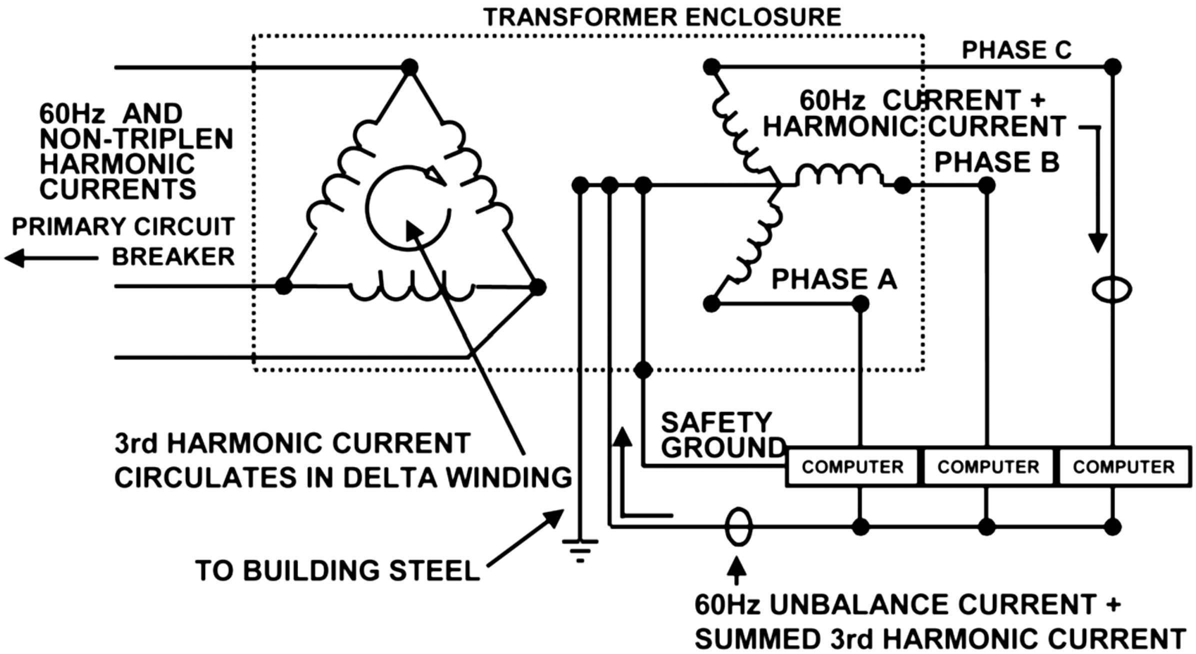
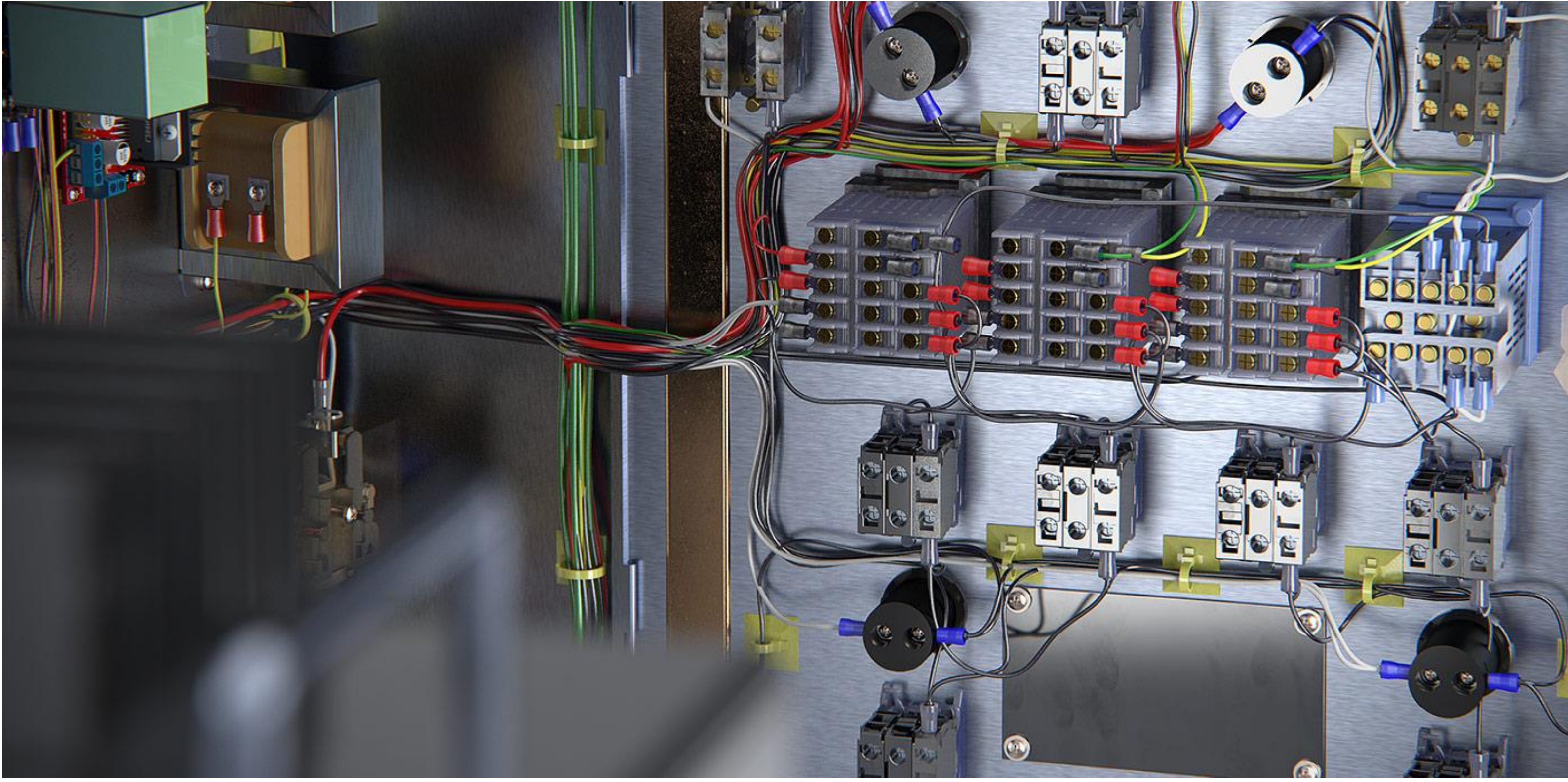


Figure 2 3 Phase system with Phase-Neutral Computer Loads.

This fact has implications for system design, since the entire electrical system must meet the national electrical code specifications for wire and conduit size. If it is expected that SMPS loads will cause high neutral currents, wires must be sized for the anticipated load. Instead of downsizing neutral wires, once common practice for a system supporting only linear loads, now neutral wires must be oversized or doubled. Larger conduit must be installed to handle more or larger wires. (Although the code permits downsized neutrals if the system is not powering non-linear loads, language in NEC 310.15(B)(4)(b, c)(2002) requires neutral conductors to be considered current-carrying conductors when nonlinear (SMPS) loads are present. It should be noted that there is no code requirement for double neutrals, only that the neutrals be properly sized for the expected current.)



Problems Caused By 3rd Harmonic Currents:

The effect of current distortion on distribution systems can be serious, primarily due to the increased current flowing throughout the system. Following are some of the problems that must be considered:

1. All distribution systems are rms current limited. For instance, a 150 kVA 208/120 wye transformer is rated for 416 rms amps per phase. The more harmonic current flowing, the less fundamental current can be supplied. Since the harmonic current does not deliver any power, its presence uses up system capacity and reduces the number of loads that can be powered. Either the system must be de-rated or a larger system, that can only be partially utilized, must be installed.
2. Harmonic currents flowing through the system wiring cause increased I^2R heat losses. This heating can increase the temperature of wires and switchgear to the point that erratic operation or even fires can occur.
3. Balanced 3rd harmonic currents cannot flow out of a delta primary. Therefore, they circulate in the primary of the transformer where they are dissipated as heat, *Figure. 2*. The current circulating in the transformer delta primary winding contributes to the load on the winding, but does not flow through the primary circuit breaker protection. Thus, the transformer primary winding can be overloaded and the breaker that is expected to protect the transformer will not do so.
4. Heat dissipated by transformers, switchgear, and wiring represents wasted energy. Energy losses, brought about by harmonic current flow, can result in significant increases in operating costs.

EXISTING SOLUTIONS

Traditional methods used to mitigate the effects of harmonic currents involve "accommodation" of the currents after they are in the system.

1. Overbuild the system to handle the extra current. Double-sized neutral wires, oversized switchgear, and transformers de-rated to less than their full capacity are examples of system overbuilding.
2. Install a k-Rated Transformer. To reduce the chance of transformer failure due to overheating, special transformers, known as "k-rated," have been designed to handle high harmonic loading, including 3rd harmonic currents circulating in the delta primary. *The k-rated transformer will survive overheating when subjected to high harmonic loading, but the harmonic currents are still present in the system*.
3. Install a zig-zag reactor, the zig-zag reactor contains special windings connected so as to present a low impedance to 3rd harmonic currents and a high impedance to 60 Hz currents. When a zig-zag reactor is connected between the phases and neutral of a 3-phase system, the 3rd harmonic currents are diverted through the device. These currents no longer flow, from the point where the zigzag is connected in the system, upstream to the transformer. *However, the phase and neutral wires from the zig-zag toward the loads still carry all the harmonic currents including the 3rd, and double neutral wires are recommended.*
4. Install a zig-zag transformer. A "zig-zag" transformer can be used to replace the standard transformer in a system. This device has the special windings of the zigzag reactor built into the transformer secondary so that the 3rd harmonic currents are cancelled in the secondary and do not circulate in the primary winding. Again*, the phase and neutral wires from the transformer to the loads still carry all the harmonic currents and double neutral wires are recommended*

Problems with existing solutions:

While accommodation methods enable the electrical system to survive harmonic currents, they have a number of shortcomings.

1. Useful system capacity is not changed. Harmonic currents still flow throughout the system wiring and rms current is not decreased.
2. Heating of wires and switchgear is not reduced. Although the temperature of transformers may be reduced, harmonic currents still flow throughout the system wiring.
3. Energy losses due to I^2R heating are not reduced. Since the harmonic currents still flow throughout the system wiring, energy is still wasted. In fact, studies have shown that the installation of certain accommodation methods may actually increase energy losses. The typical impedance of zig-zag transformers and k-rated transformers is lower than that of a standard transformer. Likewise, an oversized transformer typically shows a lower impedance than a smaller transformer. Since transformer impedance is lower, harmonic current flow throughout the system is actually increased.

OUR SOLUTION

The Centralized Smart Energy Savers works on the principle of Harmonic Suppression (Referred to as HSS), uses Voltage optimization techniques and PF Correction units to not just get rid of harmonic problems. But also, to reduce energy consumption, to increase power quality and to reduce electricity bills. On a whole, saving energy and enhancing the equipment life.

Harmonic Suppression:

Harmonic suppression in Centralized Smart Energy Saver Systems use a unique approach to mitigate harmonic currents in the distribution system. Their applications are built on principle of "Prevention is better than Cure"

The Centralized Smart Energy Saver Systems are designed to prevent the flow of harmonic currents in the distribution system, rather than treating or accommodating the currents after they are there. The Centralized Smart Energy Saver Systems consists of a parallel resistive/inductive/capacitive (RLC) network tuned to the 3rd harmonic, or 180 Hz for a 60 Hz fundamental frequency.

The electrical characteristics of this type of circuit are such that it has a very high resistance to the flow of 3rd harmonic current and a very low resistance to the flow of the fundamental 60Hz current. Application of the HSS is shown in *Figure 3*.

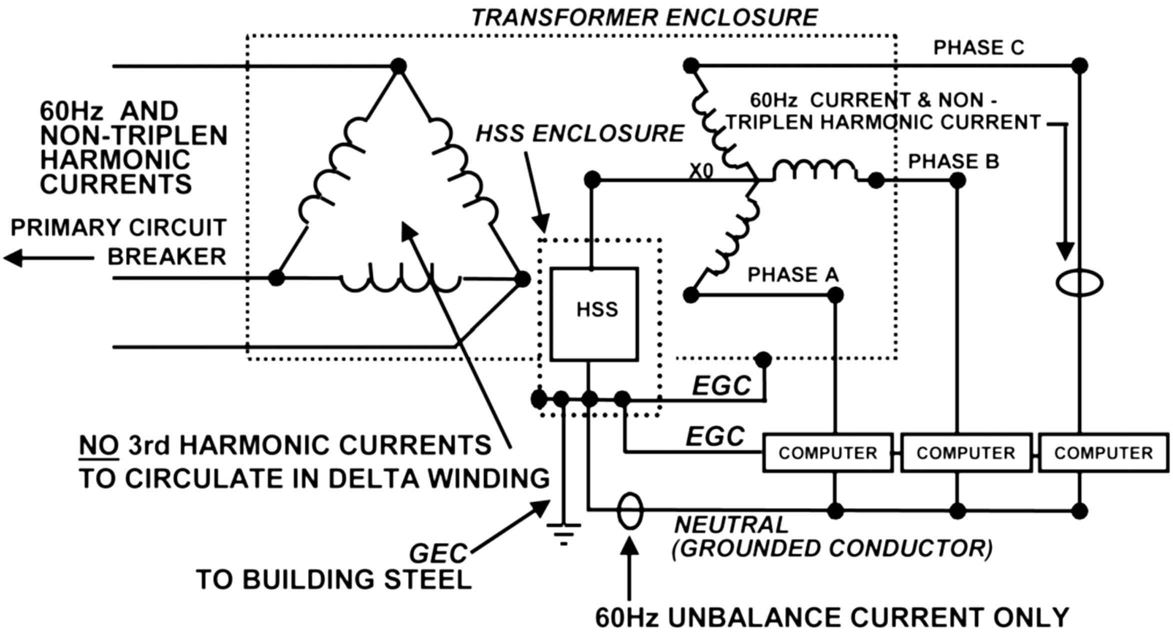


Figure 3 Phase system with Phase - Neutral loads and HSS

The Centralized Smart Energy Saver Systems is connected between the neutral wire and the 3 Hot Wires. All current that flows through the phase wires to the load must return through the neutral. If 3rd harmonic current cannot flow in the neutral, due to the high impedance of the Centralized Smart Energy Saver Systems, then no 3rd harmonic current can flow in the phase wires.

The damaging 3rd harmonic current is blocked throughout the entire distribution system from the transformer out to the furthest load. There is no 3rd harmonic current circulating in the delta transformer primary because there is no 3rd harmonic current available to circulate. The transformer is now fully protected by the primary circuit breaker against overloading.

Phase wires have more capacity available to carry useful load and double neutrals are not necessary. The neutral, for code purposes, need no longer be considered a current carrying
conductor. Overheating of transformers, switchgear, and wiring is eliminated, increasing the lifetime of all system components.

Voltage Optimization:

The Centralized Smart Energy Saver Systems uses special transformers to perform Voltage Optimization, which is a proven energy-saving technique of reducing and cleaning the electricity voltage supplied to a site, in order to:

- Reduce power losses by eliminating excessive consumption.
- Improve power quality in order to reduce wear and extend the life of electronic equipment.

When additional measures are taken such as balancing phase voltages, and filtering harmonics and transients from the supply, the process is known as Voltage Power Optimization, or VPO.

When coupled with other smart grid power management technology and Analytics Software, Voltage Power Optimization gives the end-user the ability to manage and optimize their supply in order to immediately correct power quality problems from the grid, and does so with great efficiency.

In the UK and Europe, the use of Voltage Power Optimization over the last five years has achieved average energy savings of around 13%. This effectiveness has contributed to making voltage optimization one of the fastest-growing energy saving techniques on the world market.

Many major businesses (such as Tata Consultancy Services, Kirloskar, Tata Motors, GE Healthcare, Motorola, Infosys, Ikea, etc.), and Public Sector organizations (such as Amman Municipality In Jordan, BESCOM in Bangalore, Etc.) use Centralized Smart Energy Saver Systems as a direct energy conservation measure.

PF correction:

The Centralized Smart Energy Saver Systems are integrated with power factor correction circuits. It is a technique of increasing the power factor of a power supply. Switching power supplies without power factor correction draw current in short (*Figure 1*), high-magnitude pulses. These pulses can be smoothed out by using active or passive techniques. This reduces the input RMS current and apparent input power, thereby increasing the Power Quality.

Power factor correction tries to push the power factor of the electrical system such as the power supply towards 1, and even though it doesn't reach this it gets to as close as 0.99 which is acceptable for most applications. With power factor equal to 1 or as close as possible, there are lower losses and all power generated is utilized efficiently.

- **The technical benefits:** Improved efficiency and reduction in power demand, hence a reduction in the load on the switching gear and cables, reduced costs to the consumer and support for more load.
- **Commercial benefits:** There are reduced system losses and less capital cost for the generating company. In addition, there are saving on electricity costs, since there are no charges for the excess reactive power.
- **Environmental benefits:** Reduced Co_2 Emissions.

BENEFITS

Enhanced Device Life Safety:

3rd harmonic currents flowing in the system can overload transformers, switchgear, and wiring. With neutral currents greater than the phase currents, facilities, and particularly older facilities, are at risk from overheated wiring leading to fires. Transformers with high 3rd harmonic currents circulating in the primary, and unprotected against overloading, can fail or catch fire.
By eliminating 3rd harmonic currents from the transformer to the furthest outlet, the Centralized Smart Energy Saver Systems eliminates the risk of overcurrent caused fires.

Increased System Capacity:

All electrical distribution systems are rms current limited. Harmonic currents carried by transformers, switchgear, and wiring use up system capacity that could be used to carry 60Hz currents that do work. By eliminating 3rd harmonic currents throughout the entire distribution system, the Centralized Smart Energy Saver Systems provides the facility with more useful capacity without requiring that the electrical system be upsized.

Greater Reliability:

The major cause of failure for transformers and switchgear is overheating. Random breaker tripping due to harmonic heating is well known. The elimination of 3rd harmonic currents reduces heat in all parts of the distribution system, thereby reducing the likelihood that system components will fail or trip off due to excessive temperatures.
The elimination of high neutral currents lowers neutral - ground voltages and reduces the possible data errors.

Reduced Energy and Operating Costs:

Excessive heat in electrical distribution systems means wasted energy. The heat is due to I^2R losses in all system components, and appears directly in energy bills as increased kW hour charges. Installation of the Centralized Smart Energy Saving Systems reduces I^2R Losses and the voltage optimization allows the system to deliver optimum voltage required for the loads, reducing the kWh. Saving energy between 7% to 30% based upon the load and leads to a direct reduction in energy costs.

Energy Analytics:

Energy analytics is the process of gathering electrical data with the help of software in order to assist energy suppliers and users to analyze, supervise, and optimize energy related KPIs like production costs, consumption, production distribution, and many others. By using an energy saver dashboard, one can thus improve profit margins as well as manipulate and understand large-scale trends in the industry.

CASE STUDIES

Three case studies are outlined below. In each study, neutral 3rd harmonic currents were almost totally eliminated and useful load capacity was increased. It was estimated that energy savings due to the Centralized Smart Energy Saver Systems would result in complete payback of the purchase cost in 11 to 26 months.

L'Azurde, Saudi Arabia:

Following Observations were Recorded On-Site at L'Azurde Premises in Saudi Arabia. Deployed Capacity of Centralized Smart Energy Saver System: 525 kVA for Mixed Load.

Parameters	Before	After	Remarks
Energy Consumption per Month	46529 kWh	36608 kWh	Reduced By 21%
3^{rd} Harmonic Current	1490 A	52 A	Reduced By 96.6%
Neutral Current	1510.2 A	284.5 A	Reduced By 83.57%
Power Factor	0.94	0.98	Improved by 5%
Return on Investment	0	11 Months	Huge Savings

Intel, JLL L3, Bangalore:

Following Observations were Recorded On-Site at Intel, JLL Level 3 in Bangalore. Deployed Capacity of Centralized Smart Energy Saver System: 225 kVA for Mixed Load.

Parameters	Before	After	Remarks
Energy Consumption per Month	35100 kWh	24897 kWh	Reduced By 21%
3^{rd} Harmonic Current	1156 A	67 A	Reduced By 94.3%
Neutral Current	1108 A	221.6 A	Reduced By 80%
Power Factor	0.96	0.99	Improved by 3%
Return on Investment	0	13 Months	Huge Savings

Sony Electronics, Malaysia:

Following Observations were Recorded On-Site at Sony Electronics, in Malaysia.
Deployed Capacity of Centralized Smart Energy Saver System: 225 kVA for Mixed Load.

Parameters	Before	After	Remarks
Energy Consumption per Month	1145 kWh	868 kWh	Reduced By 24.1%
Power Factor	0.94	0.99	Improved by 5%
Return on Investment	0	16 Months	Huge Savings

CONCLUSION

The Centralized Smart Energy Saver System is a well-established technology. As the case studies show, it has been embraced by a wide variety of users, including major Automobile Manufacturers, Showrooms, Shopping Complex, Electronics Manufacturers, Pharmacy Industries, Hospitals, Hotels, Resorts, IT Industries and Other Engineering Manufacturers.

In short, any group that uses non-linear Loads can benefit from this technology. The capacity and energy savings are well documented and life safety and reliability issues also are addressed. The bottom line is that the installation of a Centralized Smart Energy Saver Systems can pay for itself, by energy savings, in one to three years.

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