

APPLICATION CONSIDERATIONS FOR LED LIGHT FIXTURES IN PROCESS INDUSTRY PRODUCTION ENVIRONMENTS

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Abstract -- Light Emitting Diode (LED) luminaires provide compelling benefits such as long-term cost savings, and safety advantages through longer life and durability. LED luminaires have lower maintenance costs, and improved instant restrike capability when compared to legacy luminaire types. In industrial applications, the proven lower total cost of ownership and increased safety for LEDs are the driving forces for LED luminaires to replace traditional light sources. As with any new technology, challenges exist in designing and maintaining an optimal system to withstand the intended application and environmental conditions. Common challenges and considerations include luminaire placement, the intensity/ dispersion/quality of light, thermal management, material selection, and redundant safety and operating systems. The authors will examine best practices and common misconceptions in the selection and application of LED luminaires focusing on process and harsh/hazardous locations. The probability of success in maximizing reliability, safety & efficiency of LED technology in such applications is enhanced by utilizing proven design principles & methods. The selection methods and design principles will be explained using actual application examples and case studies.

Index Terms – Light Emitting Diode, High Pressure Sodium, Metal Halide, Color Rendering Index, L70 Lumen Depreciation Curve, High Intensity Discharge (HID), Illuminating Engineering Society of North America, Ingress Protection, Power Factor, Total Harmonic Distortion, Prevention through Design.

I. INTRODUCTION

Within an industrial facility, there are locations where high vibration, debris, chemicals, and potential explosives are present. These factors severely impact the lifetime and performance of light fixtures located within these locations. For example, operations such as aggregate processing and storage have significant dust accumulation, while other operations such as chemical processing are highly caustic environments. To ensure the safety of workers, operations and maintenance resources are needed to quickly service improperly functioning light fixtures. As lighting technology has evolved, there have been improvements in lifetime, energy efficiency, color, and safety. To ensure reliable, safe and effective performance over the life of the LED luminaire, the LED light fixture must be designed, manufactured and installed properly for use in Hazardous (Classified) and heavy industrial applications.

II. LED PERFORMANCE

A. System Efficacy

The efficacy of a LED fixture is the cumulative efficiency of its LEDs, heat sink, driver and optics. The system level efficacy of a LED luminaire is typically 25-30% less than the LED component due to losses from thermal, electrical and optical efficiency.

For example, the LED component efficacy may be in the range of 140 – 150 lumens per watt, but after efficiency losses, the total system efficacy may measure in the range of 100-105 lumens/watt. The Office of Energy Efficiency & Renewable Energy of the US Department of Energy (DOE) has estimated that the efficacy at a component level of LED technology is projected to reach approximately 220 lumens per watt by the year 2020 [1]. System level efficacy can be validated and accurately interpreted through integrating sphere and photometric test reports.

B. Lumens vs Footcandles

HID, incandescent, fluorescent and other traditional forms of lighting provide omnidirectional light. LEDs provide directional light which focuses the light to the target area.

Lumen is the amount of light output in a specific angle from a light source. A footcandle is the amount of light output from a light source in a square foot area.

The Occupational Safety and Health Administration (OSHA) Regulation 1926.56(a) [2] states: Construction areas, ramps, runways, corridors, offices, shops, and storage areas shall be lighted, with minimum footcandle levels ranging from 3 to 30 in various areas. In addition to these standards, many process industry companies have levels that are significantly greater than

the OSHA minimums.

A LED light fixture that is equivalent to a HID light fixture will have a lower lumen output than the HID fixture. This is because of light lost from the HID fixture's omnidirectional light pattern. To ensure that the proper LED light fixture is selected to maintain adequate footcandles in the work area, some LED light fixture manufacturers provide lighting layout services. These services provide renderings and reports of the expected performance of the LED light fixture in the application. This analysis is useful when site upgrades are implemented from HID to LED fixtures. For a given area, layouts for LED versus HID often times result in less required fixtures with equal footcandle performance due to the LED luminaire's directional light pattern.

III. LED SELECTION ATTRIBUTES

A. Rated vs Economic Life

Economic life is the period of operation before failure. This is based upon the LED component and the light fixture's driver lifetime. The fixture's lifetime is dependent upon the weaker of the two components, which is the driver. Per the US Department of Energy, 52% of LED light fixture failures are related to the driver/power supply [3].

Rated Life is defined as the maintenance free life of an LED fixture under worst case operating conditions during an always on, constant temperature environment.

LED lifetime is measured using lumen depreciation curves. When an LED is manufactured, it must be entered into a series of tests at 3,000, 6,000, and 10,000 hours. These tests are executed by a 3rd party to measure performance at multiple temperatures and amperages. After each testing interval, the manufacturer receives a TM-21 test report. This test report provides the specific details regarding the LED's performance. The TM-21 report uses specific calculations to define the Lumen Maintenance report (LM-80).

After the LED has been selected for the light fixture, its performance is measured to validate light output, LED junction temperature, and case temperature. The LM-80 data is used with this data to define the L70 lifetime of the LED. L70 is the number of hours after which a LED's light output depreciates by 30%.

To ensure long life, LED fixtures must be constructed with robust and durable heat sinks that allow maximum heat transfer from the LEDs to the ambient environment. For example, finned heat sinks serve as an excellent source for dissipating heat and lowering the LED junction temperature in the light fixture. Effective thermal management ensures longer life, lower lumen depreciation, and minimal color shift over the life of LED fixture. It also ensures lower surface temperature and temperature codes for safe and reliable operation in process industries with flammable gases, dusts and fibers. Fig. 1 illustrates the relationship between economic and rated life.

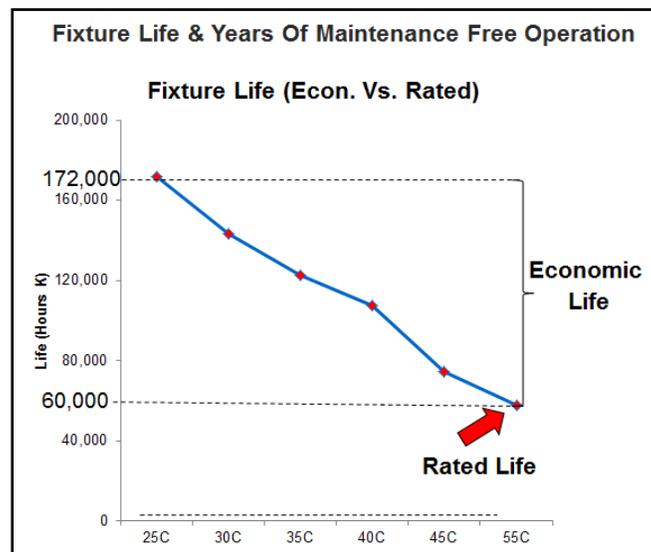


Fig. 1: Economic vs. Rated Life

B. LED vs. HID Lifetime

The average life of a High Pressure Sodium (HPS) lamp is 24,000 hours (33 months). Average life of a Metal Halide (MH) lamp is 30,000 hours (42 months). A comparable LED light fixture has an average lifetime (L70) or 100,000 hours (138

months). In addition to long life, LEDs do not utilize filaments or gases in order to generate light. This enables the LED light fixture to have superior vibration resistance and lifetime compared to High Intensity Discharge (HID). Therefore, by converting from HID to LED, industrial process facilities will realize improved lifetime and lower maintenance costs. This provides an industrial plant or mill site a safer operating environment with more consistent light output and longer fixture life.

C. *Electrical Performance*

Drivers or power supplies are utilized to energize LEDs. These devices step down incoming voltage and convert it from AC to DC. Drivers can be constant voltage or constant current output. LED fixtures designed to use constant current output isolate the LED fixture from fluctuations in current and voltage. This can result in reliable operation over time. Many drivers have surge protection which eliminates the need for additional protection devices (i.e. fuses). Redundancy in drivers can also ensure reliable operation over time. Multiple drivers connected to multiple LED circuits ensure that a light fixture will have a string of LEDs illuminated in the event any one of the drivers fails.

Within a wide input voltage range of 120-480VAC, LED drivers have very high power factors (PF) and low total harmonic distortion (THD). The most efficient power supplies will perform with a PF above 99% and a THD below 10%. These performance characteristics display how efficiently power supplies minimize interference to other electrical equipment and reduce the load on an electrical system.

D. *Energy Efficiency*

Industrial manufacturers globally are experiencing higher costs of electricity, which has inspired engineering and maintenance staffs to identify energy saving solutions. With the large installed base of HID fixtures around the world, LED light fixtures can provide significant energy savings.

Per the US Department of Energy, "The total energy use of high-bay luminaires was about 1,096 tBtu in 2012. A complete technology switch to LEDs would nearly cut this energy use in half, saving nearly 483 tBtu per year. This potential savings equates to an annual energy cost savings of US \$4.6 billion. [4]

For example, a 400W HPS industrial floodlight that is installed in a processing plant requires 464 input watts of power. With light fixtures that are spaced 30 feet apart inside a 1200 square foot area, the total fixture requirement would be 40 fixtures. At 464 watts per fixture, that creates an energy requirement of 18.6 kilo-watts (kW) per area.

A LED light fixture that provides the same light output as the 400W HPS floodlight requires 112 input watts of power. By upgrading the 40 light fixtures in the area to the LED light fixture, the energy requirement is 4.4kW per area. The LED light fixture delivers a 76% energy savings in addition to four times longer life compared to HPS. This enhances safety through reduced electrical energy load requirements. The reduction in total wattage and amperage due to the more energy efficient LED fixtures can result in lower requirements for circuit breakers, transformers and wire conductors in a process facility.

E. *Light Quality*

Due to the directional nature of LEDs, custom optics should be incorporated into the construction of the LED light fixture. Optics enables more uniform light distribution, improved coverage and minimal light loss in the work area. This enables the industrial facility to maximize application spacing and minimize the number of light fixtures required to safely illuminate the work area. Some examples of common optics utilized in industrial locations are:

- 1) *Type I* – Long and narrow beam distribution for applications such as aisles, catwalks, ramps, tunnels, long passageways, conveyer belts, loading docks etc.
- 2) *Type III* – Semicircular kidney shaped beam pattern for Narrow crosswalks or passages with wall fixtures, Tunnels with wall mount, Wall stanchion mount with 180° forward throw.
- 3) *Type V* – Circular beam pattern for Pendant, ceiling or stanchion mount overhead building, Processing mills, industrial plants, large buildings, warehouses etc.

Color Rendering - Per the Illuminating Engineering Society of North America (IESNA) [5]...measure of the degree of color shift objects undergo when illuminated by the light source as compared with the color of those same objects when illuminated by a reference source, of comparable color temperature... Color rendering indicates the degree to which a light source shows the true colors of the objects it illuminates. It is expressed in terms of a color-rendering index (CRI) on a scale of 0–100. The higher the CRI the truer people and objects look [6]. HPS light fixtures typically have a very low rating, with a CRI = 22. For example, in a maintenance area where the worker must use a black, white, and green wire, the low CRI will prevent the ability to discern between the black and the green wires and could result in improper installation.

LEDs are manufactured and tested in accordance with American National Standards Institute (ANSI) standard C78.377-2008 [7] that specifically defines color temperature and color rendering. This process is called binning. Therefore, if a processing area was replaced with a LED light fixture with a CRI of 70; it would provide the workers three times more accurate color for quality checks, reading gauge measurements, and performing precision tasks. Improved color rendering provides a safer work environment and improves workers' quality of life [8].

F. Durability and Reliability

A key factor in a LED light fixture's safety and lifetime is Ingress Protection (IP). Per ANSI/IEC Standard 60529 [9], IP is the degree of protection an enclosure has against access to hazardous parts inside the enclosure, water ingress, and solid foreign objects ingress.

LED light fixtures are commercially available that have an ingress protection level of IP66 which is zero foreign object ingress, and zero water ingress from powerful water jets. A light fixture that has an ingress protection rating lower than IP66 does not have the same performance characteristics. Robust light fixture construction that prevents failures in areas of flying debris, high pressure wash down areas is critical to safety and performance. Fig. 2 and Fig. 3 show examples of harsh industrial applications for LEDs.



Fig. 2: LED light fixture installed in potash mine



Fig. 3: LED light fixture installed in high pressure wash

IV. INSTALLATION AND MAINTENANCE

Typically, workers climb to elevated heights to install or replace lights. When climbing beyond the protection of a guardrail, fall protection must be used. The US Occupational Safety and Health Administration Regulation 1926.502(b) (1) [10] states: Top edge height of top rails, or equivalent guardrail system members, shall be 42 inches (1.1 m) plus or minus 3 inches (8 cm) above the walking/working level. When conditions warrant, the height of the top edge may exceed the 45-inch height. Two generally accepted methods to protect a worker are used while working at heights of 4 ft. or greater: personal fall-arrest systems or scaffolding with guardrails. While personal protection equipment will help protect workers from some risks, there is still a risk of injury from a fall. Therefore, Prevention through Design (PtD) concepts of elimination and substitution should be used to minimize this risk.

Human error is identified as the primary cause of approximately 85% of industrial incidents [11] [12]. To address these concerns and improve safety, new lighting installation technologies that facilitate safer and more efficient placement of light fixtures have been developed.

By replacing standard light poles with telescoping light poles as shown I Fig. 4, the PtD concept of elimination is used to physically remove the hazard. This allows the worker to safely install and maintain a light fixture where an existing guardrail provides protection.

Investing in working safety through the use of new lighting installation techniques can provide a compelling return while enhancing the safety to install and maintain LED light fixtures. When multiplied by the large number of fixtures in facilities, there is a significant savings opportunity.



Fig. 4: Telescoping light poles being installed in mine site conveyor system

V. CASE STUDY

Although there are many applications for LED luminaires in Greenfield installations across the process industries, retrofits replacing existing older technologies are also on the rise. The authors have selected on retrofit application, upgrade of the lighting for an existing mobile dragline as an example of an extremely harsh environment.

The dragline selected as a case study is an above ground coal mine located in the Western US State of Colorado. The power system at the mine is supported by a wholesale electric power supplier which is owned by the 44 electric cooperatives that it serves. The power supplier generates and transmits electricity to its member systems throughout a 200,000 square-mile service territory, across Colorado, Nebraska, New Mexico and Wyoming.

The existing dragline was operating for many years using traditional metal halide fixtures. Due to severe vibration and other environmental issues such as moisture, wide temperature variation, dust and dirt, the existing lighting presented a significant maintenance problem. Site operations could not afford loss of production or downtime due to the very high cost. Since the equipment was operated 24/7, taking unscheduled outages to replace failed components was not an option.

The mine site had been using 1000W metal halide fixtures and wanted to look at LED from a maintenance and safety

aspect. The time factor to replace fixtures on the boom and the downtime cost (several thousands of dollars per hour) of the dragline to perform this maintenance were the key driving issues.

Operations decided to replace 16 HID floodlights and install 16 LED floodlights onto the boom of the dragline shovel as shown in Fig. 5. This upgrade resulted in over \$27,000 in initial savings for the mine, including \$10,000 in maintenance savings and \$17,000 in energy savings.



Fig. 5: Mine site dragline with 16 LED floodlights installed

VI. CONCLUSIONS

Long life LEDs and new installation technologies reduce maintenance costs over time and enhance safety by minimizing the need for scaffolding and other apparatus for frequent lamp or ballast changes. The lower maintenance requirement improves safety and lessens accident probability by eliminating the risk of working at heights.

Higher energy efficient LEDs deliver significant energy savings for the facility. With many industrial facilities having a large electrical infrastructure to support lighting loads, the reduction of lighting energy consumption provides an opportunity for a lower electrical energy footprint and enhanced safety through more effective light output.

LEDs' superior color rendering compared to HID enhances quality, safety and performance in multiple areas of an industrial process facility. LED light fixtures also deliver directional light to the work area compared to HID's omnidirectional light. This maximizes light output to the work area and minimizes light loss above the fixture without the need for reflectors. These features promote workers' well-being and enrich work area safety with higher quality light allowing them to recognize and avoid hazards.

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