Introducing Connected Lighting into Hazardous Locations for Sustainability and Maintenance Optimization

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Abstract – In the recent past, process environments started their transition from lamp based technologies to light emitting diode (LED) lighting to improve lighting performance, increase lifespan, and lower electrical costs over traditional lighting such as high-pressure sodium (HPS) or high intensity discharge lamps (HID). Introducing lighting controls to further these aims in process environments has been difficult due to the complexity of the hazardous environment, code and facility requirements, installation efforts, and competing maintenance priorities causing slow adoption within facilities. This paper will describe how combining wireless radio communication and environmental sensors integrated with a facility-wide monitoring and control software solution offers new insight into plant operations. This enables identification of opportunities to further reduce energy consumption, track carbon dioxide (CO2) reduction history to meet corporate environmental, social, and governance (ESG) targets, enhance facility safety, and simplify lighting maintenance prioritization. Guidelines for optimizing lighting performance through commissioning and creating custom controls are included. Examples of practical applications of controlling and monitoring lighting in hazardous areas will be reviewed.

Index Terms — Sustainability, Connected Lighting, Luminaires, light emitting diodes, LED, Motion Sensing, Industrial Internet of Things

I. INTRODUCTION

In many process environments, facility lighting acts as a key safety system for operators. In classified locations, twenty-four-hour operation is expected while working under extreme environmental conditions. Facilities with continuous processing need reliable lighting while operators are in the area. Lighting is installed everywhere operators work and placed to illuminate around dense piping, raised walkways, warehouses, and control rooms. Over the long term, lighting maintenance is very complex to manage due to the quantity of luminaires over a large installation.

In locations with reduced workforce and/or automated operations, maintenance teams have limited time to solve lighting issues. According to the January 2022 U.S. Bureau of Labor Statistics Labor Turnover Summary [1], there are 855 thousand manufacturing openings. Lack of staffing impacts when and what maintenance work occurs. This reduces opportunities for lighting maintenance until turnarounds or shutdowns occur. Extra complications arise for lighting classified environments. In addition to securing maintenance team availability, there is the cost and complexity of securing hot work permits, additional safety gear, and scissor lifts or cherry pickers. Often lighting fixtures are installed above machinery where regular maintenance is difficult. In some cases, planning is required years in advance to ensure maintenance is possible.

II. STATE OF LIGHTING IN HAZARDOUS AND MARINE APPLICATIONS

For any product – including lighting - extending product life is key to reducing the long-term costs associated with operation and maintenance. The introduction of dimming into LED lighting allows operators to make choices to best illuminate their facility while reducing the total operating time of the luminaire. Reducing the operating time of lighting directly correlates to extension of product life while reducing energy consumption. Automation of lighting controls in connected lighting has the additional benefit of adding consistency to lighting operations. Legacy lighting types like HID and HPS cannot be dimmed or turned off reliably, and therefore the life of their lamps cannot be extended.

Reducing energy consumption and carbon dioxide production are key metrics for improving sustainability in today's process industries. Lighting can play a key role for environmental sustainability. By itself, the operation of LED lighting greatly reduces energy consumption when compared to legacy lighting types like HPS or HID lamps and furthermore, the addition of sensors and controls in connected lighting produces further opportunities to reduce energy consumption. Utilizing onboard sensors for motion and illuminance allow for the luminaire to dim its LED driver output when operators are in the area and/or when there is available daylight.

Energy consumption benefits for connected lighting directly relates to the avoidance of reductions in carbon dioxide. The EPA sets the national marginal emission factor is estimated as 7.09 × 10-4 metric tons CO2/kWh [2]. Transitioning to connected LED lighting adds up as decreases in energy consumption correlations to reduction in greenhouse gas and CO2 emissions. While generator loads are constant across variable loads, the % of power consumed for LED lighting will decrease. Facility engineers can then evaluate sizing decisions for generators for that location as well as potentially adding new loads on that generator.

Continuously monitoring and recording lighting energy consumption and usage provides facility managers the ability track carbon dioxide emissions over time and simplify their reporting. A system level analytical control software system can monitor and calculate the energy consumption of each luminaire over a long period of time. In aggregate, avoidance of carbon dioxide can be calculated as a difference to legacy lighting systems.

For example, in a typical mid-size oil refinery, up to 4000 luminaires are installed. Traditional industrial lamp-based technologies like HIPS typically consume up to 547W per luminaire. [2] LED technology has improved luminaire energy consumption by up to 70 percent. One example is a 70W 5,300 lumen HID lamp consumes 94W when taking in account ballast inefficiencies. This HID lamp can be replaced by a single 3,300 lumen luminaire that consumes 28W.

Connected lighting offers further energy optimization in industrial environments by adding multiple options for controls to further decrease energy consumption by up to 65% [2]. Analytical control software monitors and analyzes usage data to calculate carbon reductions from connected lighting.

LED lighting also improves over traditional lighting by eliminating the regular replacement and disposal of burned-out lamps over the life of the LED luminaire. There is significant cost of scheduling the work with appropriate permits and subsequent disposal. This cost gets multiplied across the entire facility as lamps burn out regularly.

III. FACILITY WIDE ANALYTICAL CONTROL SOFTWARE SOLUTION FOR LIGHTING

The Industrial Internet of Things (IIOT) has expanded significantly into process industries because of the added value that analytics may bring to facility management. A facility-wide analytical control software platform allows operators to view the operating state of instruments in different process areas. Lighting is unique because it is installed high above the process area. For example, task lighting is typically mounted up to 40ft in height. It is very difficult to assess the operating state of a luminaire once it is installed.

Combining lighting controls and reporting with an analytical software solution is ideal because operators now interact with a single software solution. Operators benefit from similar user interfaces between applications, common training, long term support and a secure upgrade process across all devices in the network.

Adding redundancy to the system is vital to ensure there is no single point of failure. With lighting being a key safety system, assurance in operation is required. A connected luminaire requires built in failsafe modes where if loss of connectivity occurs, the light output returns to full strength. Likewise, if the main server goes offline, the luminaire must operate on its own until the server comes back online. As part of a larger control system, lighting and other instrumentation will encounter the same connectivity issues at the same time, and standard operating processes will alert the facility personnel to correct disruptions.

Operators have unexpectedly encountered poor lighting conditions in remote locations and limited use sites. Now with the benefits of continuous monitoring, maintenance managers can routinely determine the state of lighting in remote locations before operators encounter poor lighting. Predictive maintenance benefits operators when the analytical control software can alert users before something fails based on monitored performance.

IV. SECURE AND RELIABLE COMMUNICATION

When selecting a connected luminaire for harsh and hazardous location, selecting the right communication protocol is important. Wired protocols require additional installation costs for cable, design complexity, and labor to install. A wireless solution is superior due its plug and play nature. Utilizing common wireless mesh protocols in process industries such as IEEE 805.15.4 [3] or IEC 62591:2016 [4] has significant benefits for connected lighting. This simplifies the whole installation as connected lighting can reuse the existing gateway infrastructure, commissioning tools, design guidelines, and customer support used by other devices.

A mesh protocol benefits connected luminaires due to its self-healing mesh-based communication. A mesh protocol routes data around obstacles back to the mesh protocol gateway. Since lighting is installed above the process area, a connected luminaire can communicate by line of sight directly with process instrumentation, other connected lighting and form a strong connection back to the gateway antenna. Connected lighting is line powered so no battery replacements are required to maintain a wireless connection.

A mesh protocol offers robust encrypted communication using 128-bit AES encryption, it also uses combination of multiple keys for broadcast & point to point communication encryption.

A mesh protocol device's status and alert messages enable the analysis of diagnostic data from connected lighting. For example, trends in the changes of the internal temperature and humidity of the luminaire can inform operators if the installed location exceeds the luminaire rating. Historical data like the run time hours of the LED driver is available to inform future operators when it is time to replace the driver. This data can inform maintenance teams during the planning stage of the next turnaround to assess lighting in the space.

Furthermore, commissioning a connected lighting installation is simplified with a map-based commissioning software. Maintenance managers, energy officers, and lighting designers can upload images or schematics of the facility and assign the lighting and controls to the designated area. By grouping lights of similar type and function together in software, consistency in lighting operation is maintained. Over the life of the facility, lighting needs will change. For example, during turnarounds, more operators and contractors will be on site than during normal operation. More lighting is needed during round the clock operation than during normal operating time. Likewise, when new equipment is installed, connected lighting's flexibility allows the space to be recommissioned for light levels and operation.

V. PRACTICAL APPLICATION OF LIGHTING CONTROL

A – Test installation description

One installation of Connected Lighting was done at a specialized metal foundry in the United States. At this foundry, a foundry modernization program has been a priority over the past several years to improve safety, process optimization, and sustainability. This facility includes four new melt furnaces with automated lines with an in-house annealing oven process. The melt furnaces can melt up to four tons of ductile iron per hour. Overall, this facility employs 118 personnel during three shifts a day.

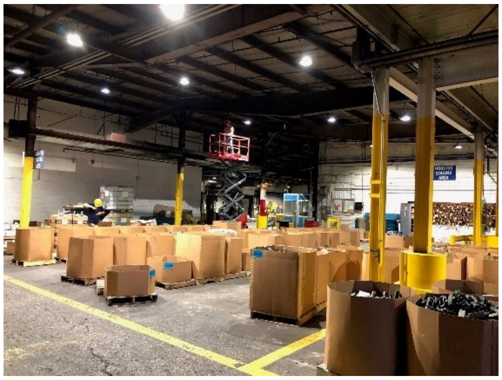

Figure 1: Shipping Area

Reducing facility energy usage is key for foundry optimization because of its energy intensive processes. Implementing a software solution to record and analyze energy data ensures that the benefits from energy upgrades are tracked.

B – Options Investigated

A key part of any lighting upgrade is a lighting site survey. A walkdown was completed to assess the lighting needs of each area in the facility. When a walkdown occurs, lighting engineers are toured though the subject facility, and quantify the number and type of existing luminaires. Lighting engineers use laser rangefinders to determine room dimensions, and ceiling heights. The site maintenance lead and lighting engineers reviewed the traffic usage in different locations, and measured incidence light levels utilizing a handheld light meter in key working locations. Mapping the light level and height under each luminaire and at key workstations provides the needed data for calculating the appropriate luminaire intensity. This data is then entered into lighting modeling software to virtually map the space and place simulated luminaires at different mounting heights. Simulations are run to determine the lumen intensities of each luminaire and where they should be mounted.

After surveying the site, the shipping area was selected due to heavy use during main shifts but limited in use during overnight shifts. The currently installation of luminaires are kept on 24 hours a day. Twenty-six connected LED luminaires were installed on the ceiling in the shipping area with different lumen intensities based on mounting height. Areas with inconsistent usage are prime candidates for connected lighting because they offer the option to dim lighting when operators are not present. The other opportunity for lighting optimization was from sunlight from exterior windows and garage doors. The ability to dynamically change the light level based on available light was also possible.

In the shipping area, there is a main walkway connecting the office area with the foundry, and a perpendicular walkway for forklift and foot traffic between the loading dock and the shipping area. Grouping lights of similar capabilities that are installed in close proximity together ensures the best lighting experience. Operators need to know that connected lighting is reliable and predictable.

By adding wireless lighting motion controls, lighting usage can be reduced safely when operators are not in the area in a secure and robust manner. Traditionally, a single wired motion sensor would control a series of luminaires. The wired motion sensor can only sense motion in its own range, and have blind spots where operators are not detected. With wireless motion sensors, each luminaire can have its own integrated motion sensor. When each luminaire can distinguish motion, operators can be locally detected to inform the luminaire to increase their LED driver output to its maximum preset level.

When connected to a wireless mesh network, the luminaire shall signal back to an analytical control software on its change in motion, and the analytical control software sends a turn to high dim level message to the rest of the luminaires in the group. When motion is no longer detected after an acceptable time, the light levels are reduced to a minimal light level as determined by the lighting site survey. In the shipping area, groups of lights were set to 100% intensity when motion is detected. Later, after a period with no motion being detected by any luminaire, the groups of lights are dimmed down to 20% intensity until motion is detected again

Another option for lighting control is daylight harvesting. This solution works best in areas with access to available sunshine or any other external source of illumination. As the sun sets, the luminaire light output increases proportionally to the available ambient light level. For outdoor installations, even on the sunniest of days, the light levels can change with clouds, sun position, or storms. Daylight harvesting can maintain a more consistent light level at the work surface. The luminaire has extensive sampling and normalization routines built in to avoid spurious events affecting the luminaire light levels. In the foundry, there is a bank of windows where the sun shines through half the day. Nearby luminaires were set in daylight harvesting control modes through the analytical control software. The luminaire levels change significantly over the day but maintain consistent lighting in the space. Connected lighting can also be controlled by a time-based schedule. By specifying turn on and turn off times, the lighting can be switched on during operating hours and dimmed during off hours. Key considerations for schedule control are locations that run regular hours or specific luminaire styles solely needed like nighttime flood lighting. One such location was in the middle of the shipping area. Due to lighting output overlap of multiple lighting, the middle luminaire dimmed in the daylight hours. Connected lighting benefits from being on a wireless network because of the ability to synchronize device clocking across all luminaires. Even in the case of loss of wireless signal, each individual connected luminaire still maintains their internal clocks to maintain synchronization.

Dimming is also a safety improvement in favor of controlled lighting, Fixtures with dimming controls can provide a controlled dimming rate from a low light output to full output to mitigate possible night blindness situations. This improves on simply having a motion triggered standard light where a person at night might trigger the lighting in an area and have it transition from low output to max output instantly. The foundry operates all day and ramping the lighting output reduces operator strain during turn on events.

In some locations, lighting controls can have limited benefit. In the shipping area, the shipping desk station where operators interact with computers, printers, and scales the entire day. Due to this being a primary workstation, the decision was made to keep the overhead luminaires on all day long

C – Realized Benefits

After the initial commissioning was completed, the benefits of an analytical control software became apparent. Several weeks after installation, the shipping area lighting was revaluated based on several factors: Incident light levels, sustainability, use of the space, and operator and supervisor perception.

Remeasurement of lighting levels with the newly installed connected luminaires set to maximum light level confirmed that the measured incidence level met the simulation plan. Light levels improved over the entire space and eliminated dim spots on the edge of the space.

After the installation and commissioning, the analytical control software records and analyzes the usage data of the connected luminaires. Tracking the changes in light output patterns over time for different lighting groups show how motion and light data influence luminaire operation.

By adding connected LED in the shipping area, the reduction in energy consumption for two lighting groups set to group motion control was calculated to be up to 43%. When motion is not detected, the light output was set to 20%, and increases the LED output to 100% after motion was detected by any motion sensor. This area is very active over its three work shifts, but there is significant amount of time each day when lighting usage can be curtailed.

Daylight harvesting was also evaluated on two connected luminaries installed near the windows on the side of the shipping area. In this configuration, the connected luminaires saved up to 75% of energy. There is no need to over light the area if the available sunlight is strong enough to maintain light levels.

Calculation of the energy savings and CO2 reduction is straightforward in the analytical control software because of the built-in analytical software. As the system scales up on site in quantities of connected lighting, the energy savings become significant.

The perception of the facility personnel was that the shipping area was unused during the evening, but usage data from the main walkway showed that shift changes triggered changes in lighting levels. Another key finding was the discovery of no usage on Sunday evening when the foundry was not operating. This gave the local team confidence in the connected lighting system because operators did not encounter a dark room or felt that light was lacking. Analytical control software platform employed in harsh industrial environments also enabled remote monitoring of system performance by the testing team, and more importantly, was able to provide regular insight into the reduction of lighting usage and energy consumption

D- Future Possibilities

This installation of connected lighting was limited to a single location within the foundry. Expanding lighting monitoring further in other parts of the facility is possible because more capital improvements for automation are planned. As energy costs per kWh and maintenance costs increase over time, further focus will be placed on ways to reduce energy consumption. For example, areas within the foundry still require upgrading to LED technology. Further rapid expansion of connected lighting is feasible because the base network and analytical control software are already in place.

VI. CONCLUSIONS

Recent innovations in connected LED lighting for harsh and hazardous locations has created new ways to monitor lighting for sustainability, energy consumption, facility usage, and device health. These have not been able to be applied in harsh and hazardous environments before because of dimming limitations in traditional lighting technologies. Utilizing an analytical control software to communicate with connected lighting through secure wireless protocols simplifies network design, installation, and operator training. Connected lighting's flexibility in controls and lighting performance ensures it can meet the lighting needs over the life of the facility and can aid the optimization of maintenance planning.

VII. ACKNOWLEDGEMENTS

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VIII. REFERENCES

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IX. VITAE

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