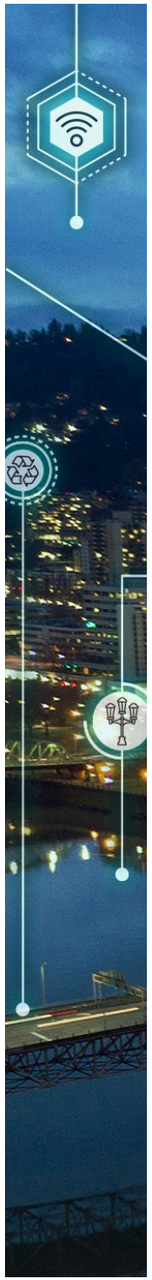

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How do we utilize the remote monitoring capabilities of connected lighting systems to facilitate automated fault detection, diagnostics, and prediction?

Michael Poplawski,
Pacific Northwest National Laboratory

Lyn Gomes,
DPR Construction
Building Commissioning Association

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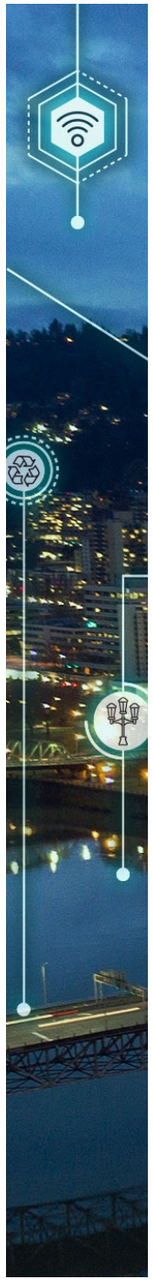

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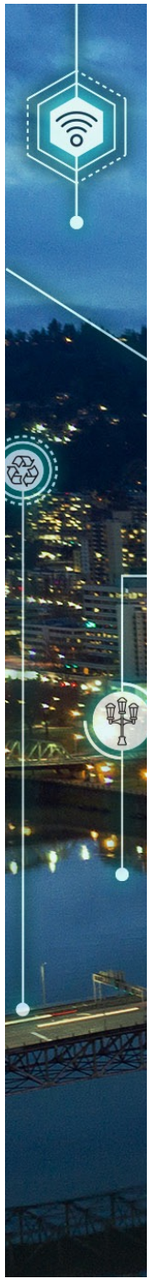
Agenda

- What is the goal of automated fault detection and diagnostics (AFDD) for lighting systems?
- How do commercially available lighting systems enable AFDD?
- Does the lighting industry need to do anything to realize the potential of AFDD?
- What is the relationship between AFDD and commissioning?
- Does the commissioning industry need to do anything to realize the potential of AFDD?
- Questions for you, questions for us!



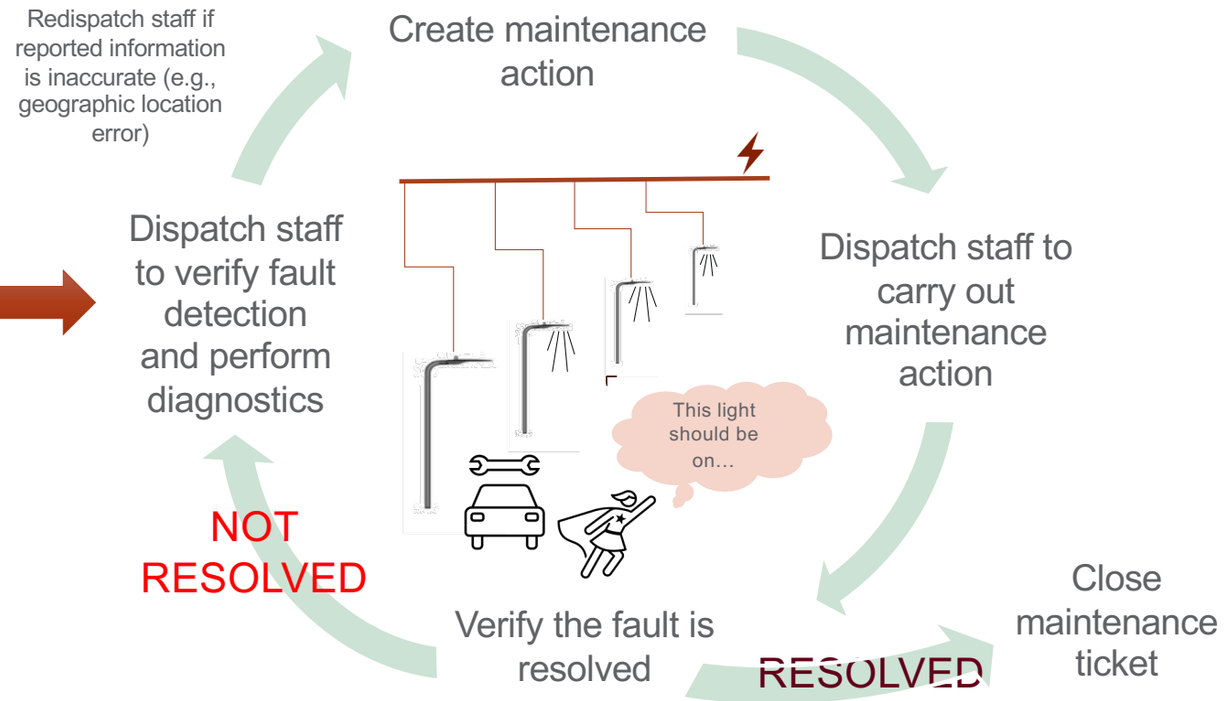
Lighting system maintenance is often inefficient due to reliance on human fault detection and multiple maintenance staff dispatches

Fault Detection

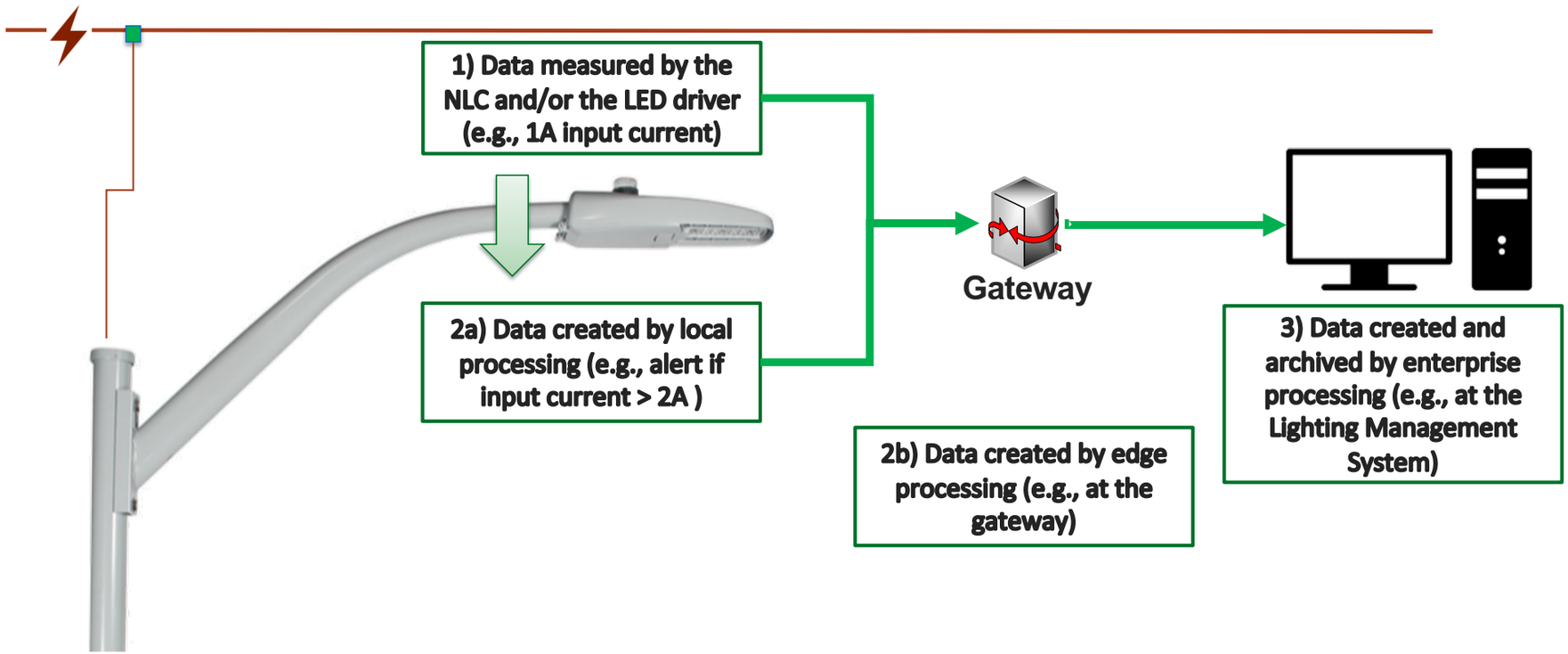
Reported by maintenance staff during scheduled inspection

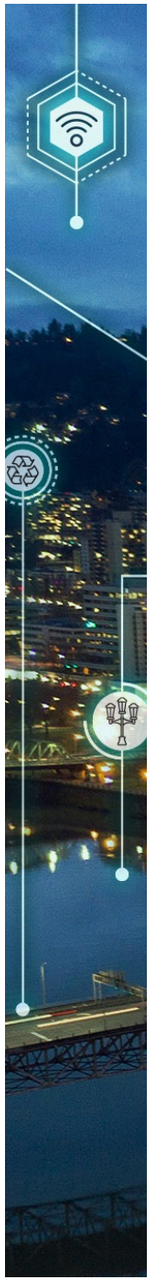
OR

Reported by occupants/residents, often leading to duplicate reports (i.e., reports of the same problem by multiple people)



Lighting systems can remotely monitor and report data about their operating environment and status





46/72 of current DLC listed “Networked Lighting Controls” claim “Remote Diagnostics” capabilities

Product ID: NYUR4HHE4G7

Remote Diagnostics	
Has Remote Diagnostics	Yes
Characteristics remotely monitored, diagnosed, and/or reported	Communication Issues, Status: online/offline devices, Device errors, Component failures, Remaining component life, Load Shed Status
Types of alerts	Email notifications, GUI alerts, GUI map of offline devices, GUI page, Outage reports

Product ID: NFPAJ5M1DVC

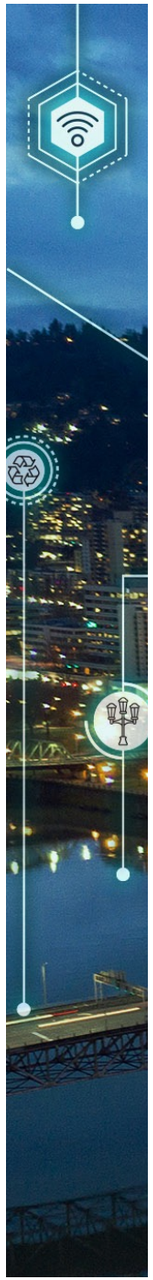
Remote Diagnostics	
Has Remote Diagnostics	Yes
Characteristics remotely monitored, diagnosed, and/or reported	Status: online/offline devices, Device errors, Component failures, Remaining component life
Types of alerts	GUI alerts

Product ID: NSLVR23CNTRL

Remote Diagnostics	
Has Remote Diagnostics	Yes
Characteristics remotely monitored, diagnosed, and/or reported	Device errors
Types of alerts	GUI page, API alarms

Product ID: NIR9JRJH8MZ

Remote Diagnostics	
Has Remote Diagnostics	Yes
Characteristics remotely monitored, diagnosed, and/or reported	Battery Level, Communication Issues, Network Signal Strength, Status: online/offline devices, Device errors, User Defined
Types of alerts	Blinking local LED status lights, Email notifications, GUI alerts, GUI map of offline devices

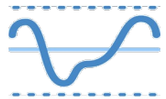


Monitored data can be used to automate fault detection and diagnostics, and determine the most appropriate maintenance action(s)

REMOTE MONITORING

- Energy consumption
- Power draw
- Active energy load
- Power factor
- Mains voltage
- LED driver output voltage & current

FAULT DETECTION



- High voltage alert
- Low voltage alert
- High current alert
- Luminaire failure

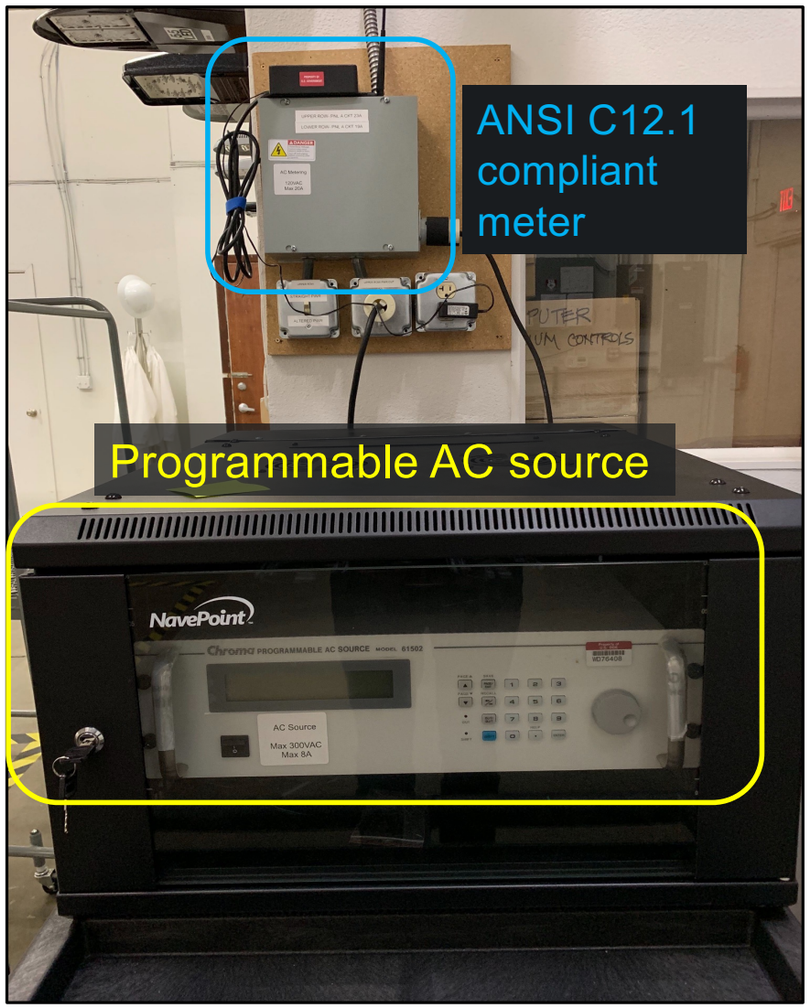
FAULT DIAGNOSTICS

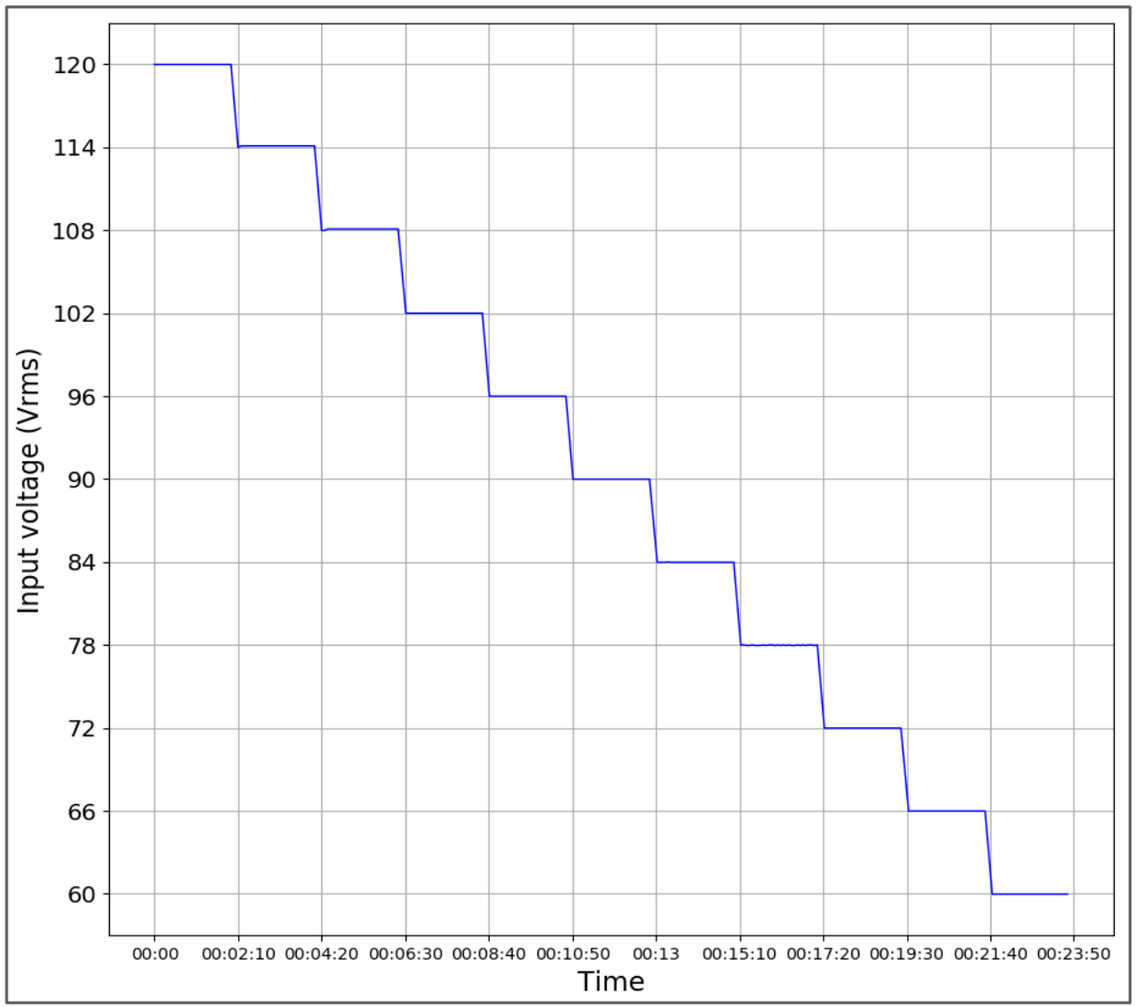
- LED driver failed
- Electrical disturbance on the distribution system
- Failure to communicate
- Other disturbance

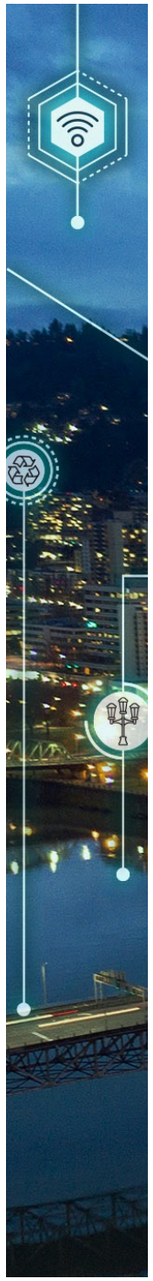
Maintenance Action

- Repair
- Replace
- Adapt, Optimize

Is it straightforward to diagnose the cause of faults from setting thresholds on monitored parameters?







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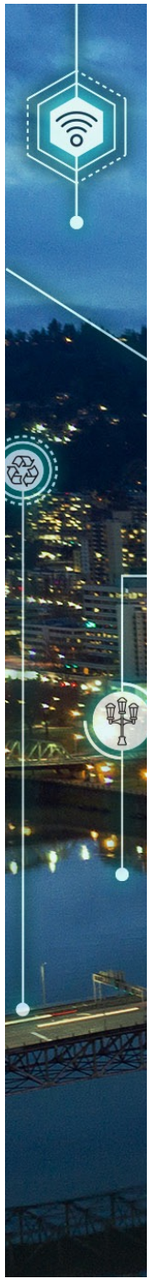
Potential Fault Detection Schemes

- When the luminaires were exposed to the 10 undervoltage conditions, all 12 performed as expected between 120 VAC and 102 VAC, by drawing increased current to maintain a constant power draw.
- As the voltage dropped below 102 VAC, luminaires started demonstrating undesirable behavior that might be viewed as service interruptions
- Three fault conditions were defined:
  - High Current Fault - was detected by determining if the relative input current draw of a luminaire or its LED driver exceeded 120% of its rated value.
  - Low Light Fault - was detected by determining when luminaire relative power dropped below 95%.
  - Intermittent Output Fault – was detected by observing the light output (strobing, no light), but can be detected by determining when luminaire input current draw changes by 20 percentage points twice in a minute?



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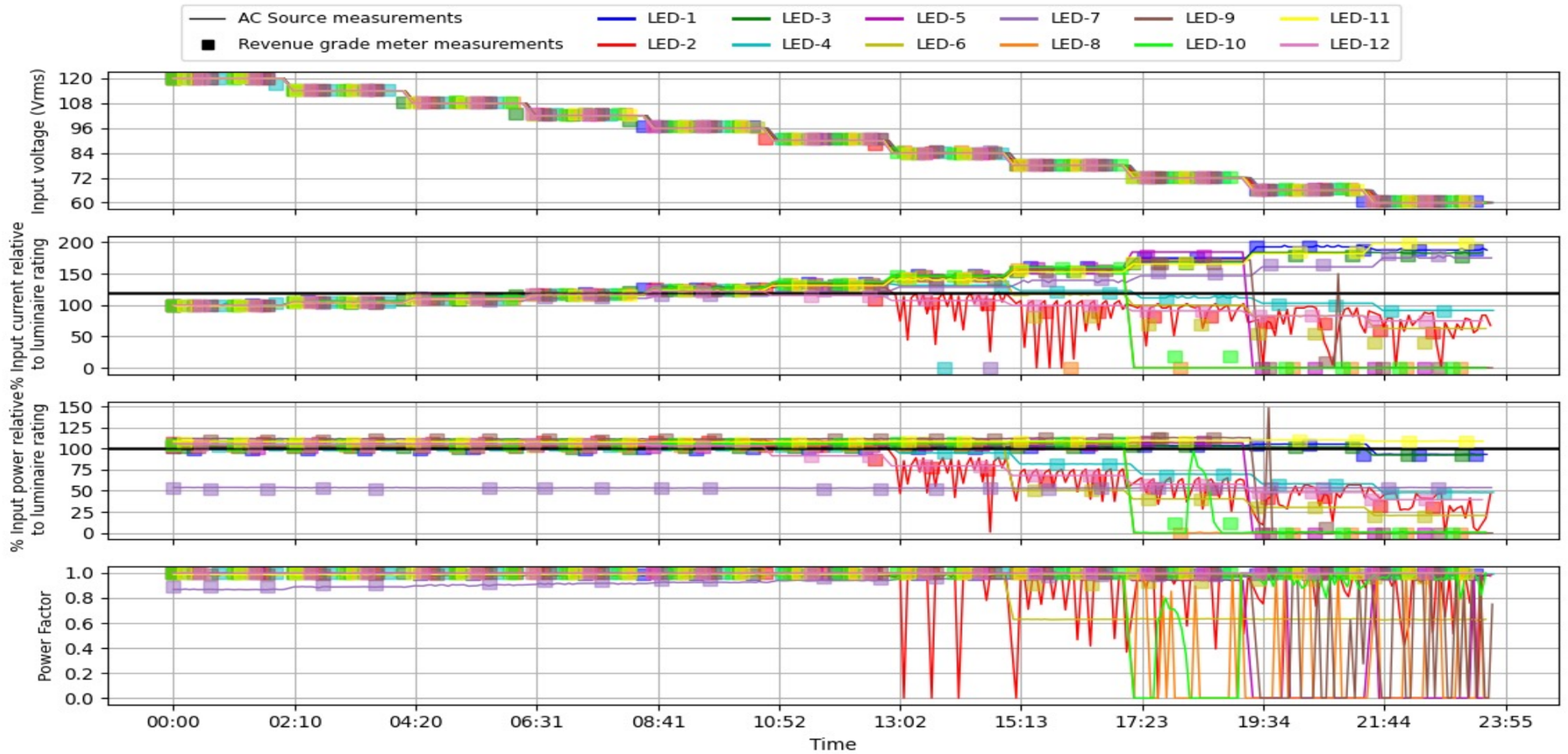
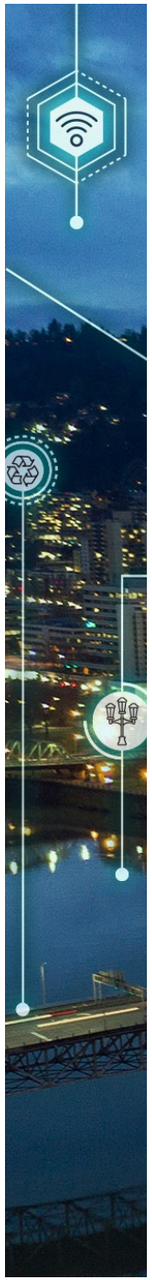
All tested luminaires compensated for the undervoltages by increasing their current draw and thus exhibiting the “High Current” fault at voltages below 102 V





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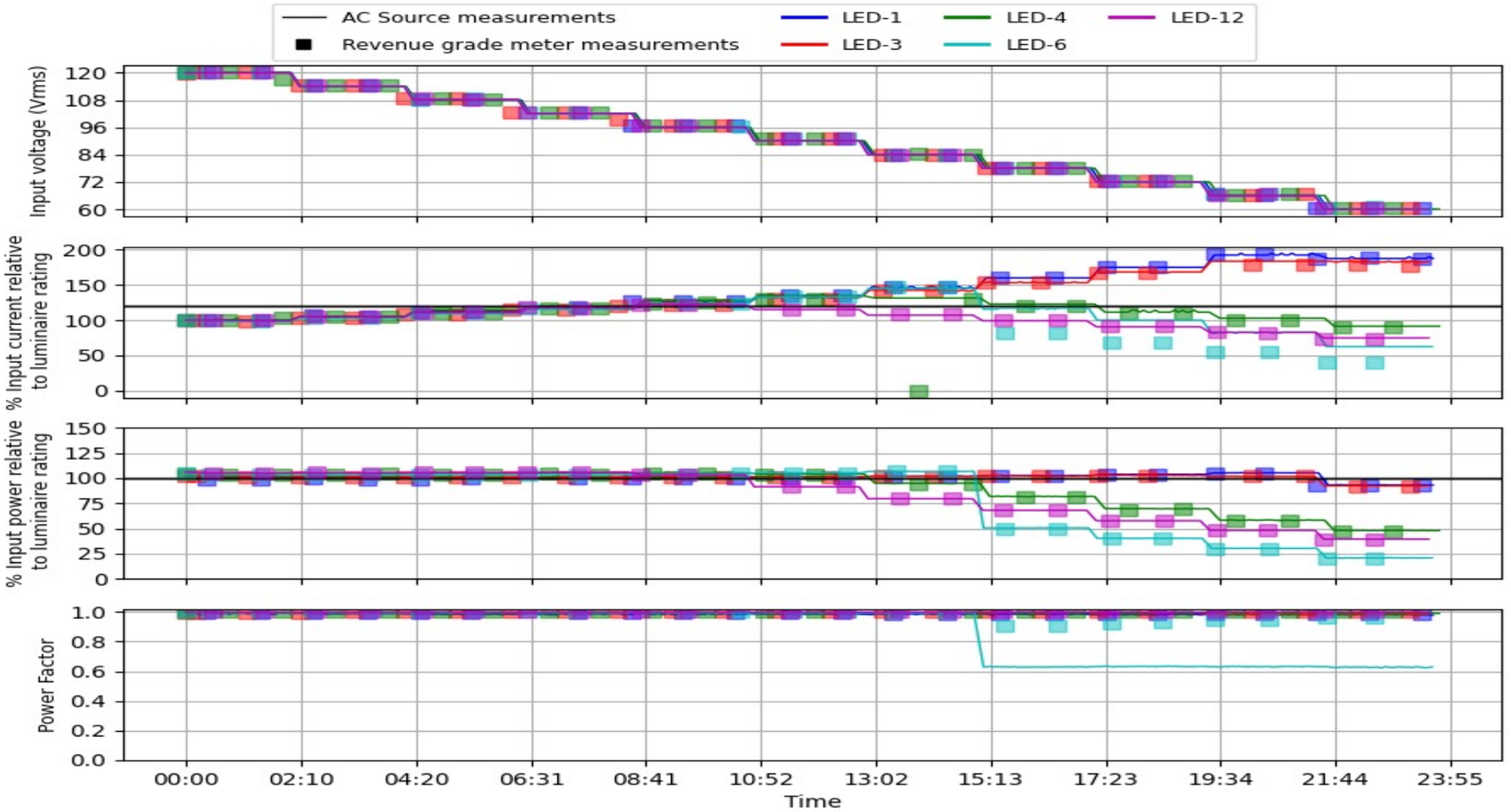
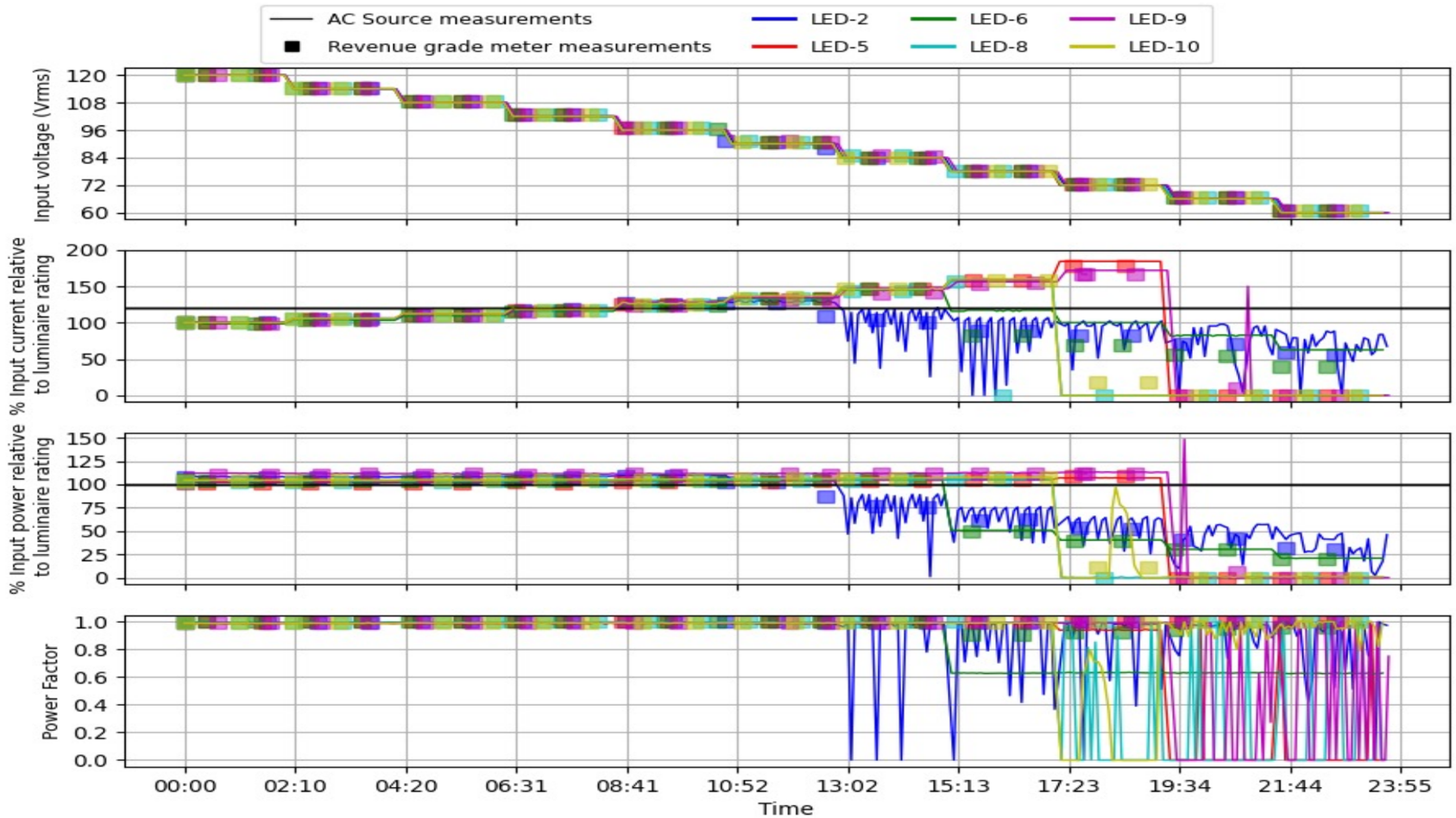
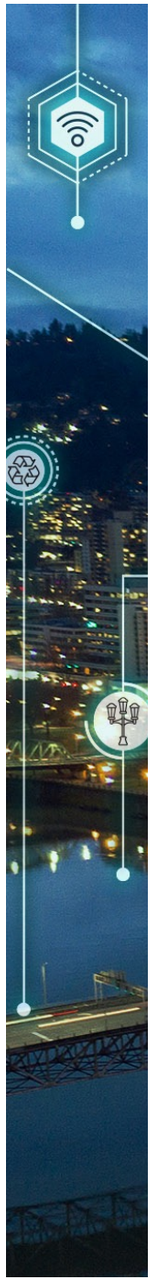
5 out of 12 luminaires exhibited a “Low Light” fault as self protection mechanisms are implemented by driver manufacturers to prevent driver failure high current



6 out of 12 luminaires exhibited an “Intermittent Output” fault by strobing or turning OFF at a given input voltage below 84 V





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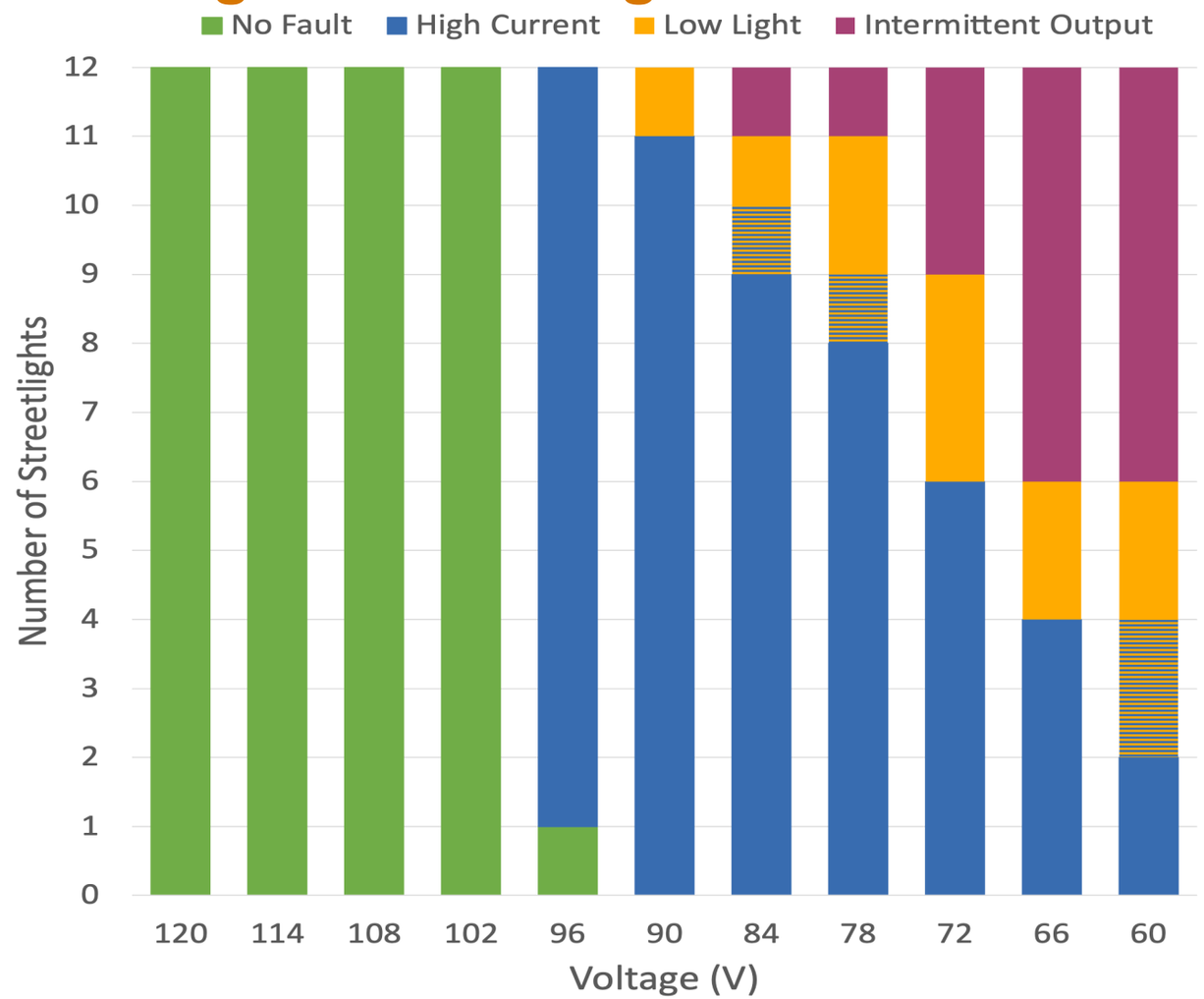
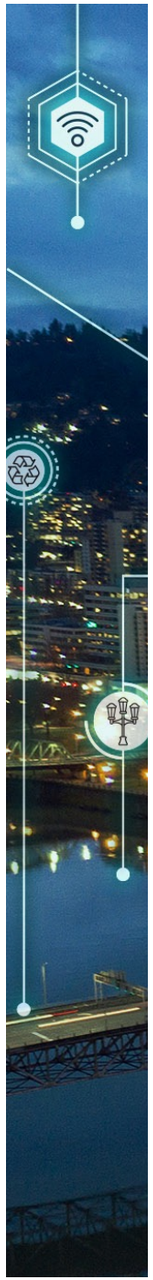
Undervoltage conditions can results in (at least) three types of faults, and a single “Low Voltage” threshold is not sufficient for detecting or discerning between them

- All tested luminaires performed as expected for first 4 test conditions between 120 V and 102 V by increasing their current draw to compensate for voltage drop
- These faults can be detected by setting thresholds for one of the monitored data variable which corresponds to the service provided or can be used as a proxy for the service.





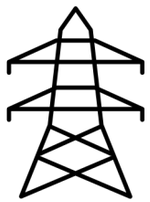
Do we need common definitions for key terms? What is a Fault?

- A FAULT is a SERVICE INTERRUPTION that occurs when an instance of an asset that provides a specific service fails to function as intended.
- For example, a luminaire is an asset that provides light/illumination service. So, any situation where light is not being delivered as intended can be described as a LUMINAIRE FAULT. The specific way in which the service deviates from nominal can be described and named.

Some Luminaire Faults	
OFF: Lights OFF when supposed to be ON	ON: Lights ON when supposed to be OFF
INTERMITTENT: Light is turning ON/OFF in an unintended way	WRONG LIGHT: Lighting level does not meet occupant needs or standards for service and/or safety
NON-OPERATIONAL: Luminaire does not turn on when power is applied	NETWORK INTERFACE: Luminaire turns on when power is applied but does not communicate on the internal /external network

A lighting system is comprised of multiple pieces of equipment that provide specific services

Device: Network
Service: Communication



System: Electrical Distribution
Service: Electrical AC Power

Device: Luminaire
Service: Illumination (i.e., controlled and appropriate light)

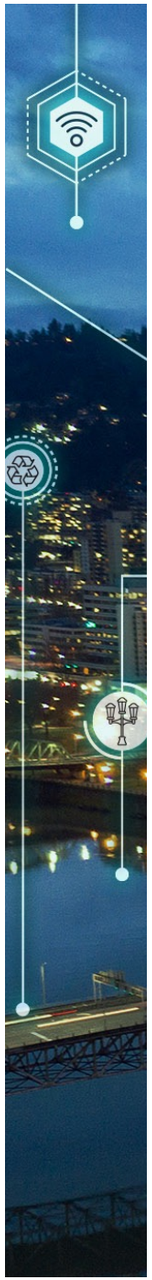
Device: Networked Lighting Controller (NLC)
Service: Control

Device: Sensor
Service: Data

Device: LED Driver
Service: Electrical DC Power

Device: LED Module
Service: light

Fixture/Enclosure
Service: Mechanical support and electrical grounding



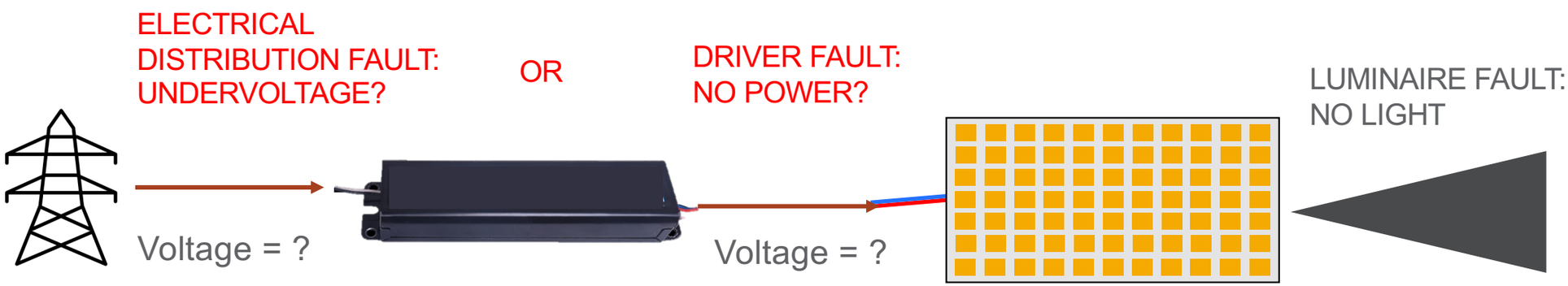
When describing, naming, and defining faults it is helpful to ask the following questions

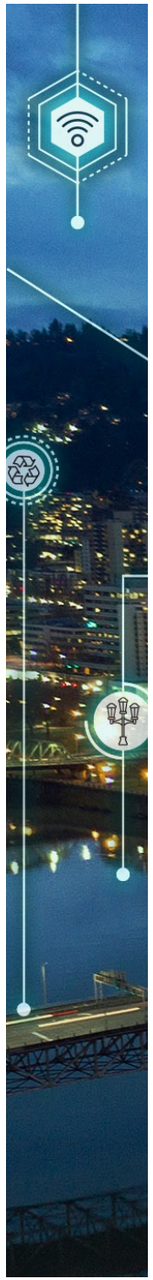
1. What device or system is experiencing a service interruption? {ENTITY}
2. In what way does the service deviate from what is intended? {TYPE}

- Luminaire Example
  - The LUMINAIRE is experiencing a service interruption → LUMINAIRE
  - Light is turning ON/OFF in an unintended way → INTERMITTENT
  - Fault name: LUMINAIRE: INTERMITTENT
- NLC Example
  - The CONTROLLER is experiencing a service interruption → CONTROLLER
  - The external communication network is functioning as intended, the NLC draws electrical power but does not communicate with the LMS → NETWORK INTERFACE
  - Fault name: CONTROLLER: NETWORK INTERFACE

Each piece of equipment that comprises a lighting system can have faults

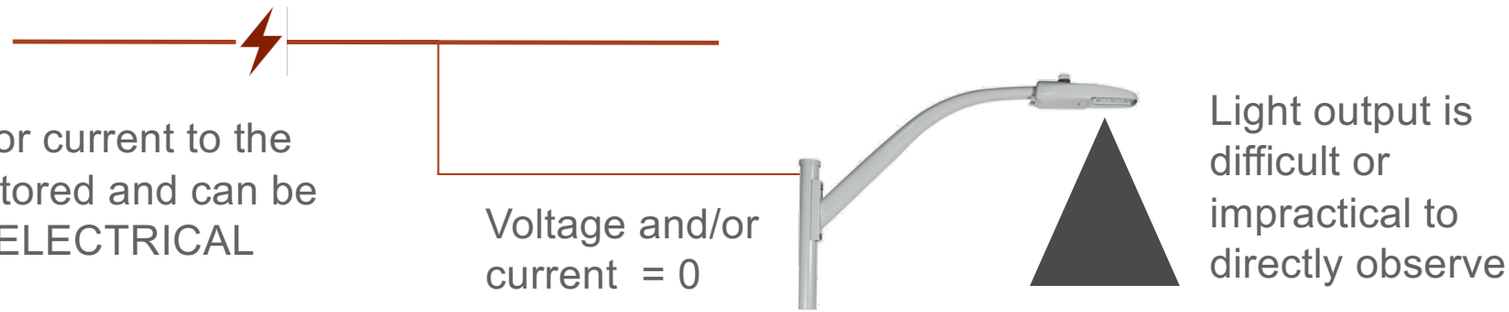
- Faults in one device can cause or be caused by faults in other devices
- For example, a LUMINAIRE: NO LIGHT could be caused by DRIVER: NO POWER or ELECTRICAL DISTRIBUTION: UNDERVOLTAGE

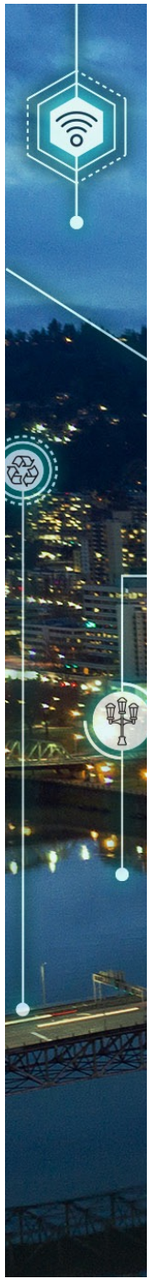




Do we need common definitions for key terms? What is Fault Detection?

- FAULT DETECTION is the process of determining that a FAULT has or may have occurred and then subsequently labeling it.
- In many cases, the service provided by an asset cannot be directly observed. In such cases it may be possible to observe/measure conditions related to service, use those observations as proxies for service, and determine that a fault MAY have occurred.





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Examples of conditions that can be readily measured and monitored by commercially available lighting systems, and used for detecting lighting system faults

LED Driver

Input Voltage, Current, Power, Energy, Power factor, Output power, Open/Short Circuit, Temperature

LED Module

Temperature, Hours of Operation

Lighting Controller

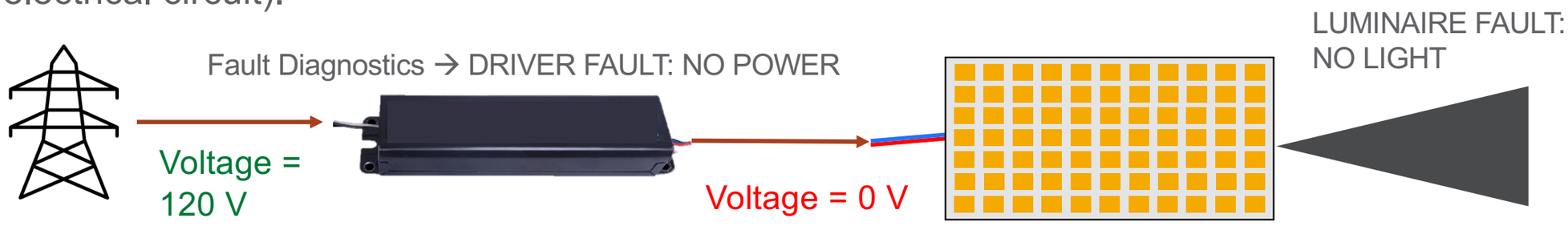
Input Voltage, Current, Power, Energy, Power factor, Network Connection Status

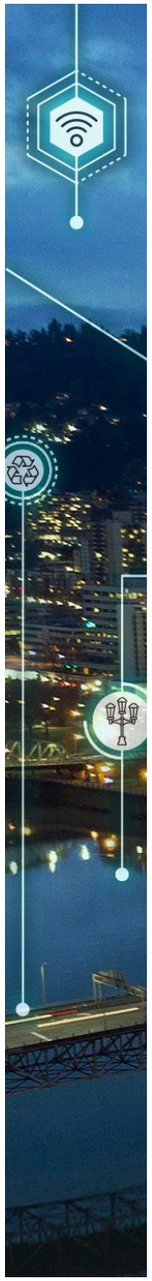
Metadata

Location, ID Number, Rated Input power

Do we need common definitions for key terms? What is Fault Diagnostics?

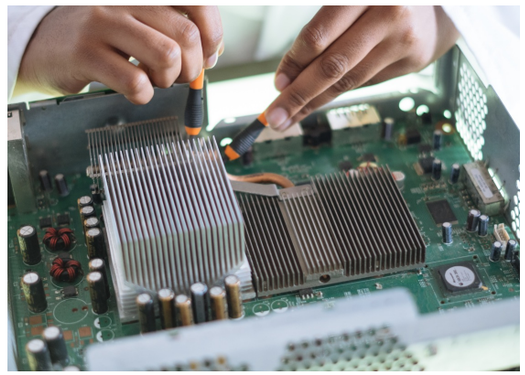
- FAULT DIAGNOSTICS is the process of determining the cause of the fault and the most appropriate MAINTENANCE ACTION to clear the fault and restore service.
- In many cases, one result of a fault diagnostic for a system or device is the determination of fault in another system or device.
  - For example, the LUMINAIRE: NO LIGHT fault might be caused by a ELECRICAL DISTRIBUTION: UNDERVOLTAGE fault or a DRIVER: NO POWER fault
- In many cases, fault diagnostics requires consideration of more than one measured condition, contextual information related to the fault (i.e., metadata), and information about nearby devices that have shared dependencies (e.g., other luminaires powered by the same electrical circuit).

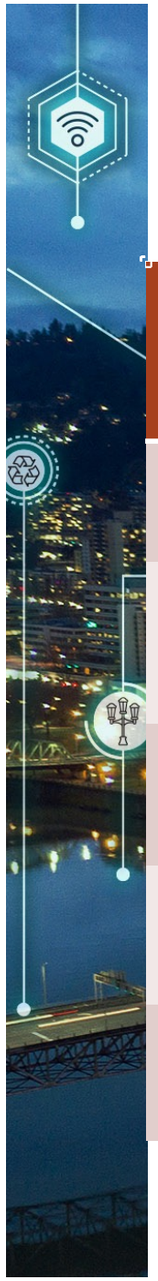




Do we need common definitions for key terms? What is a Maintenance Action?

- A MAINTENANCE ACTION is a specific, suitable activity undertaken with a goal of restoring service.
- MAINTENANCE ACTIONS may or may not restore service; their likelihood of doing so is dependent on the quality of the fault diagnostics. In many cases, the fault diagnostic might only suggest one or more maintenance actions that might restore service
- Some possible maintenance actions may be deemed to be not suitable for some maintenance actors. For example, some maintenance actors cannot or choose not to do field repair or cannot or choose not to repair luminaires in the field or in a laboratory setting.





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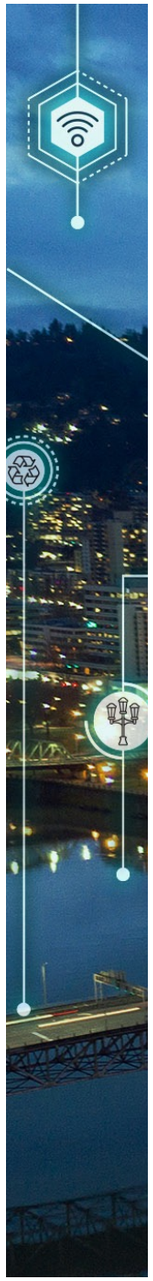
Lighting System Faults

Luminaire (Light)	Lighting Controller (Control Signal)	Enclosure	Electrical Distribution System (AC Power, Voltage)	Driver (DC Power, Voltage, Current)	LED Module (Light)	Sensor (Data)	Network (Communication)
ON: light is ON when supposed to be OFF	NO CONTROL: no-control signal is being applied	INTEGRITY: one or more electrical connections are lost	NO POWER: system is not providing any power	NO POWER: driver input voltage is as expected and can communicate on the internal network [e.g., DALI], but is not providing any power	NO LIGHT: LED module input voltage/current/power is as expected, but is not providing any light	NO DATA: sensor is not generating any data	NO EXTERNAL NETWORK: devices cannot communicate with the external network
OFF: light is OFF when supposed to be ON	WRONG CONTROL: control signals are being applied but not as intended	GROUND: ground is not present or disconnected	UNDERVOLTAGE: voltage is below threshold value	WRONG OUTPUT: driver input voltage is as expected and can communicate on the internal network [e.g., DALI], but is providing output voltage/current/power above or below threshold value	WRONG LIGHT: LED module input voltage/current/power is as expected, but the lighting quality does not meet occupant needs or standards for service and/or safety	WRONG DATA: sensor generates data but is not performing as expected	NO INTERNAL NETWORK: devices cannot communicate on the luminaire internal network
INTERMITTENT: light is turning ON/OFF in an unintended way	NON-OPERATIONAL: lighting controller does not turn on when power is applied	OPTICS: optics are occluded enough to reduce light output	OVERVOLTAGE: voltage is above threshold value	NON-OPERATIONAL: driver does not turn on when power is applied		NON-OPERATIONAL: sensor does not turn on when power is applied	WRONG EXTERNAL NETWORK: devices can communicate with external network, but the external network is not performing as intended
NETWORK INTERFACE: luminaire turns on when power is applied but does not communicate on the internal/external network	NETWORK INTERFACE: controller turns on when power is applied but does not communicate on internal/external network	MIS-WIRE: Swapped/incorrectly wired cables		NETWORK INTERFACE: driver turns on when power is applied but does not communicate on the internal/external network		NETWORK INTERFACE: sensor turns on when power is applied but does not communicate on the internal/external network	WRONG LUMINAIRE INTERNAL NETWORK: devices can communicate on the luminaire internal network, but the internal network is not performing as intended
WRONG OUTPUT: lighting quality does not meet occupant needs or standards for service and/or safety							



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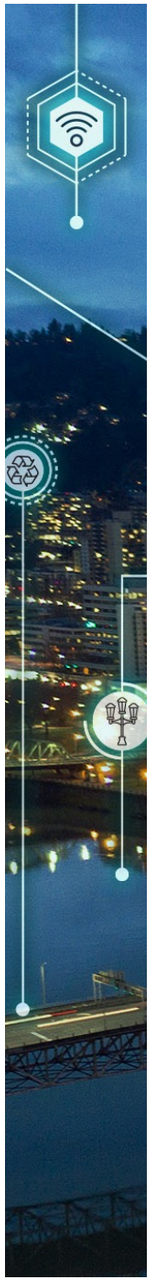
Lighting System Maintenance Actions

Luminaire	Controller	Enclosure	Electrical Distribution	Driver	LED Module	Sensor	Network
Repair electrical connections	Reset/power-cycle	Repair electrical connections	Reset/power cycle	Reset/power-cycle	Repair electrical connections	Repair electrical connections	Repair external network
Replace	Update firmware	Replace internal wiring	Repair electrical connections	Update firmware	Replace	Replace	Repair Luminaire Internal Network
	Recommission controller	Repair optical component	Replace distribution components	Repair electrical connections			Replace Luminaire
	Repair electrical connections	Replace optical component	Restore generation source	Replace			Replace Controller
	Replace	Repair mechanical enclosure					



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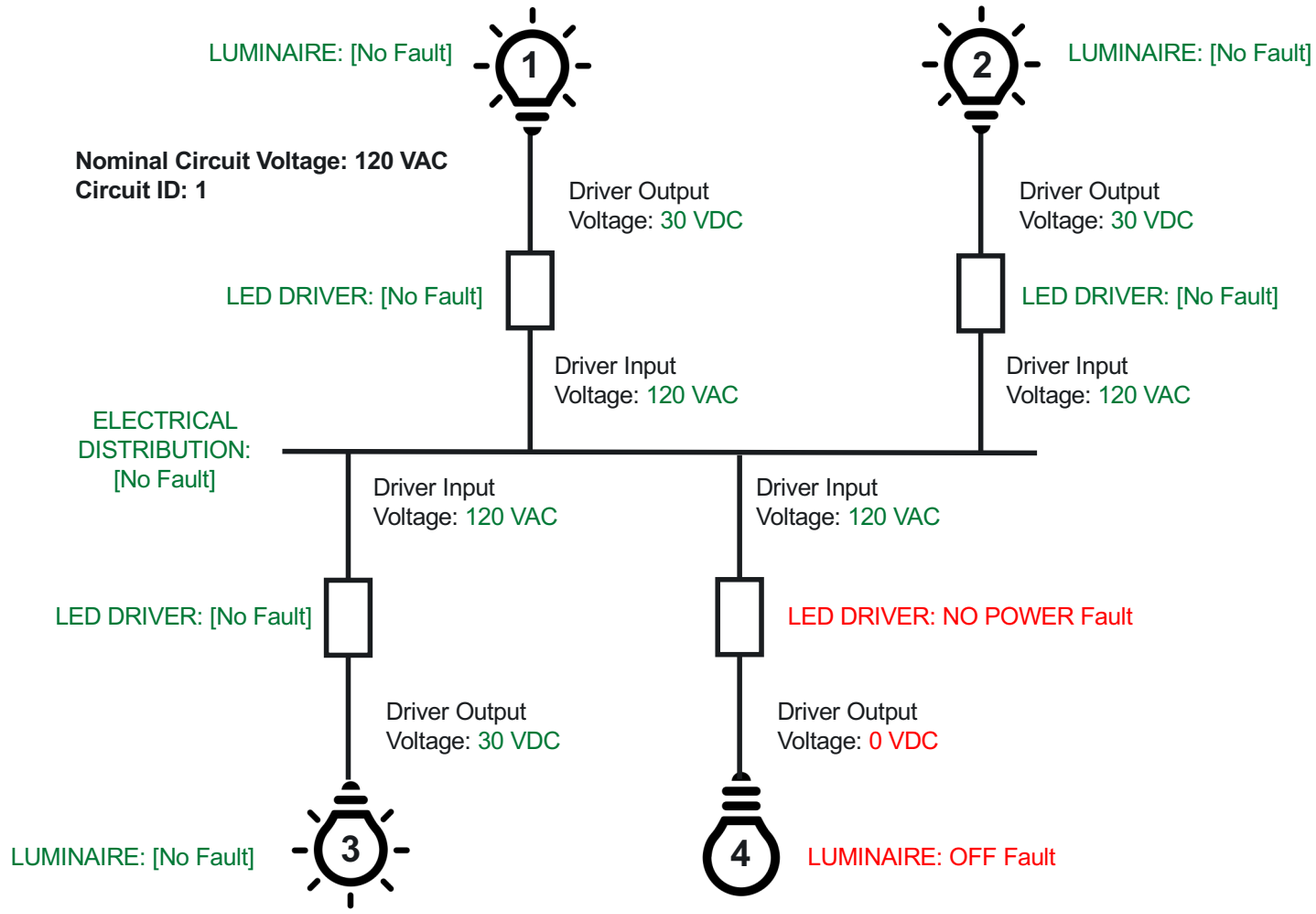
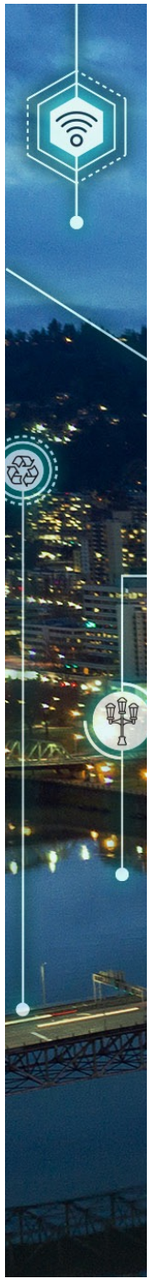
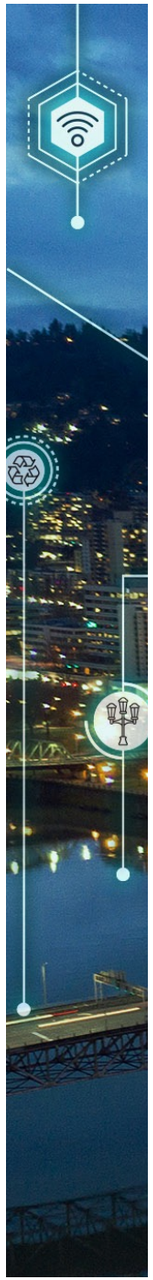
Example Lighting System





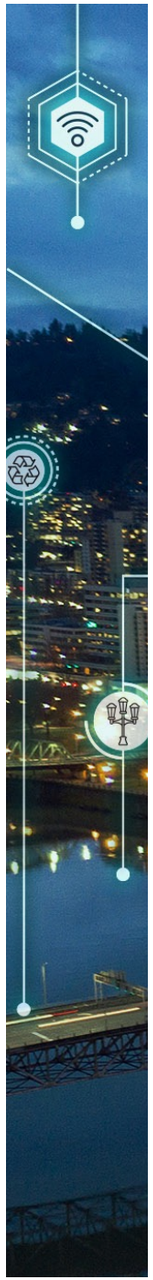
Example: Fault Detection

- Four luminaires in the ceiling grid all on the same circuit. During the daytime employees are using the conference room when one of the four lights suddenly turns off. This is a service interruption of a single luminaire that is OFF when it should be ON therefore, a LUMINAIRE: OFF fault has occurred.
- Light output is not measured so other measurements are used AFDD of the LUMINAIRE: OFF fault.
- One available AFDD input might be LED driver input voltage. In this example, the voltage is within range so not fault is detected
- Another available AFDD input might be LED driver output voltage. In this example the LED driver output voltage is measured as zero, which the AFDD might discern to be a LED DRIVER: NO POWER fault



Example:
Fault Diagnostic and Maintenance Actions

- Once the LED DRIVER: NO POWER fault is detected the LUMINAIRE: OFF fault can be DIAGNOSED to be caused by a faulty LED driver. The maintenance actor (e.g., building manager) cannot perform repairs directly on the LED driver. Three possible maintenance actions are identified:
  1. Reset or cycle power to the LED driver
  2. Replace the LED driver
  3. Replace the luminaire
- The most appropriate maintenance action is determined by evaluating the possible maintenance actions:
  - If the LED driver can be remotely reset or power to the LED driver can be remotely cycled, then option 1 may be the most appropriate initial maintenance action, as it requires the least effort and cost.
  - If option 1 is not possible or unsuccessful, then option 2 may be the most appropriate maintenance action, as it requires less cost than option 3 and may require less effort than option 3 if the LED driver is easy to replace.
  - If option 2 is deemed too costly, not viable, or unsuccessful, (e.g., a replacement LED driver is not readily available, removal of the LED driver requires too much effort) then option 3 may be the most appropriate maintenance action.



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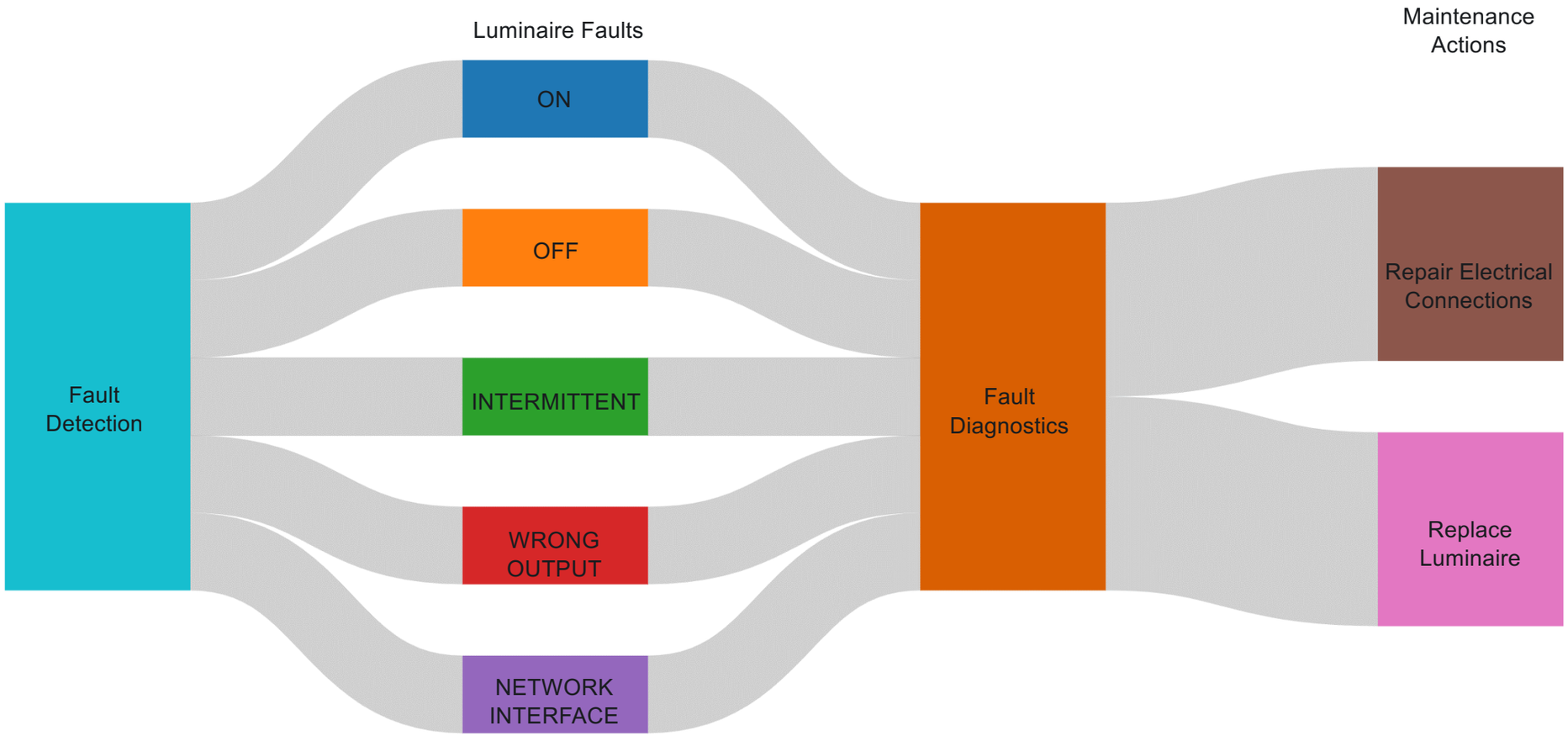
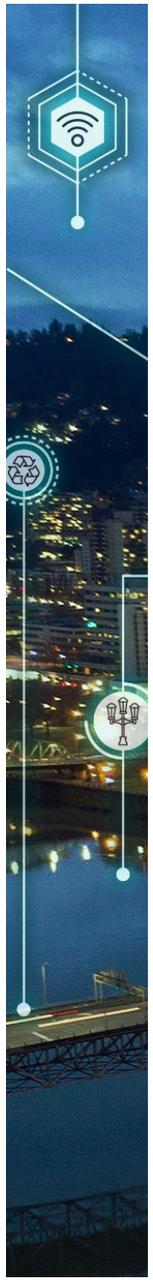
Luminaire Faults & Maintenance Actions





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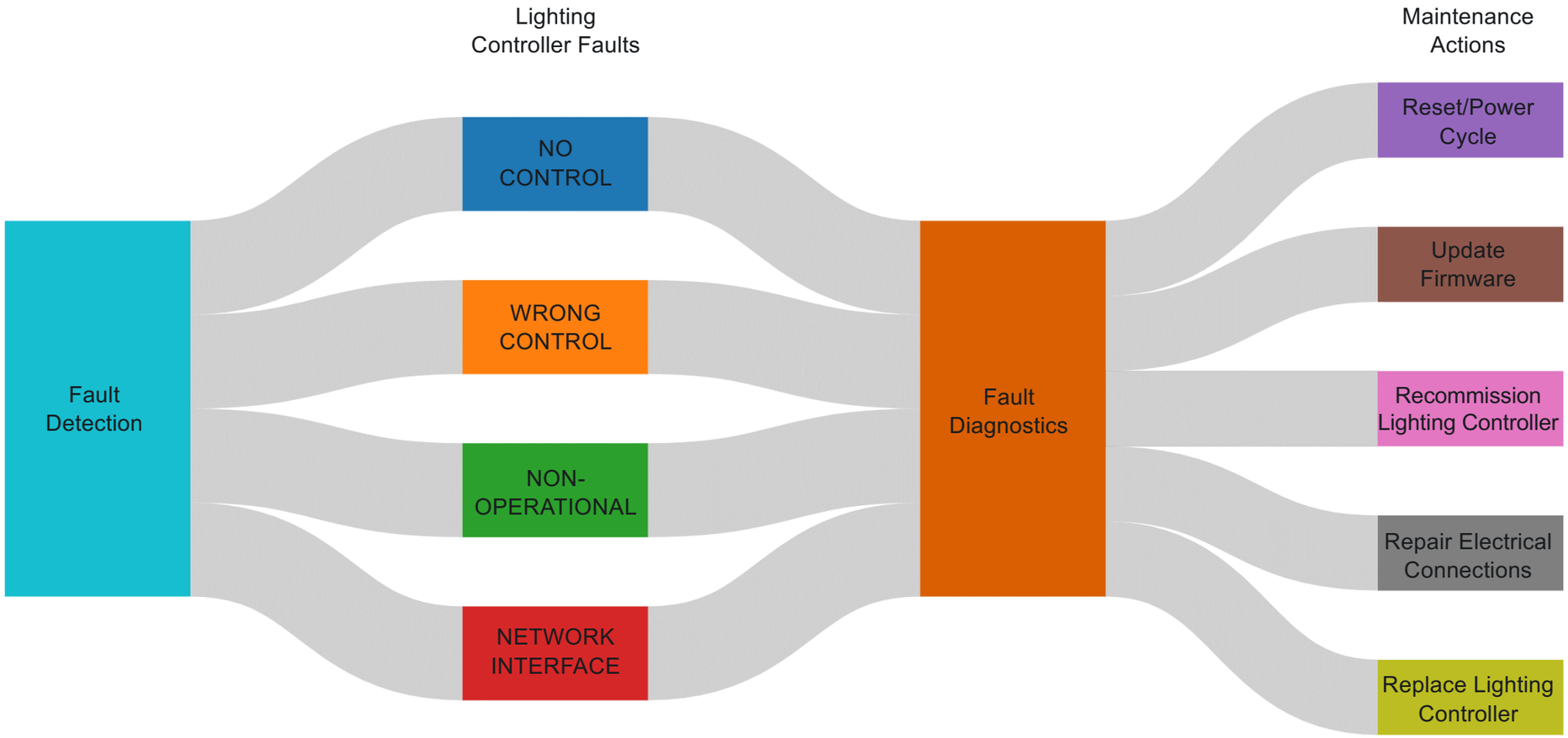
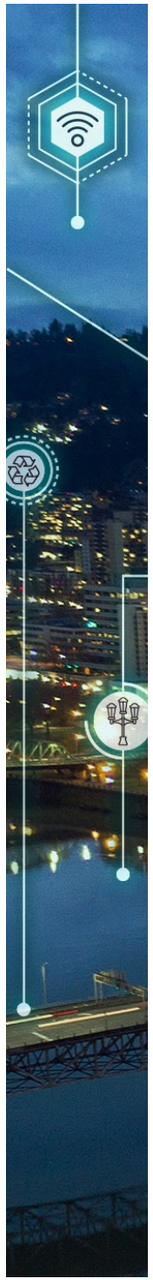
Lighting Controller Faults & Maintenance Actions





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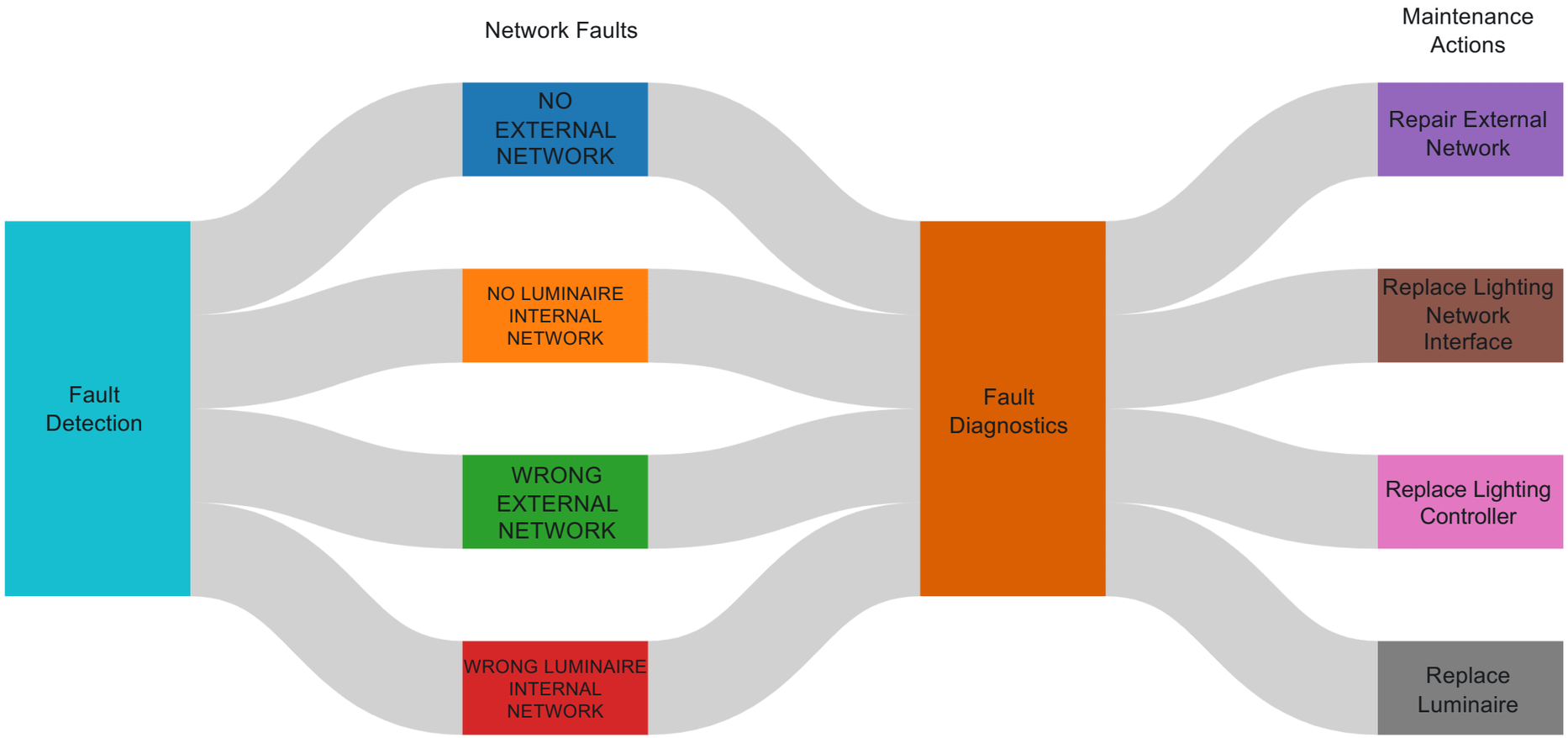
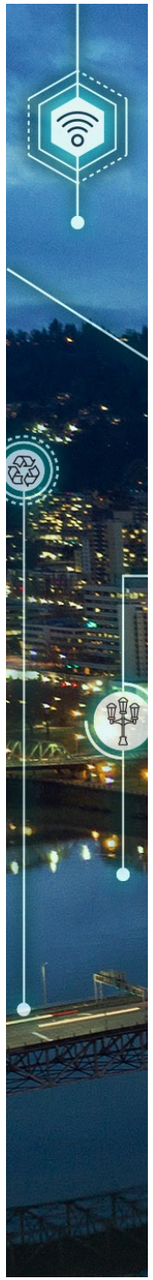
Network Faults & Maintenance Actions





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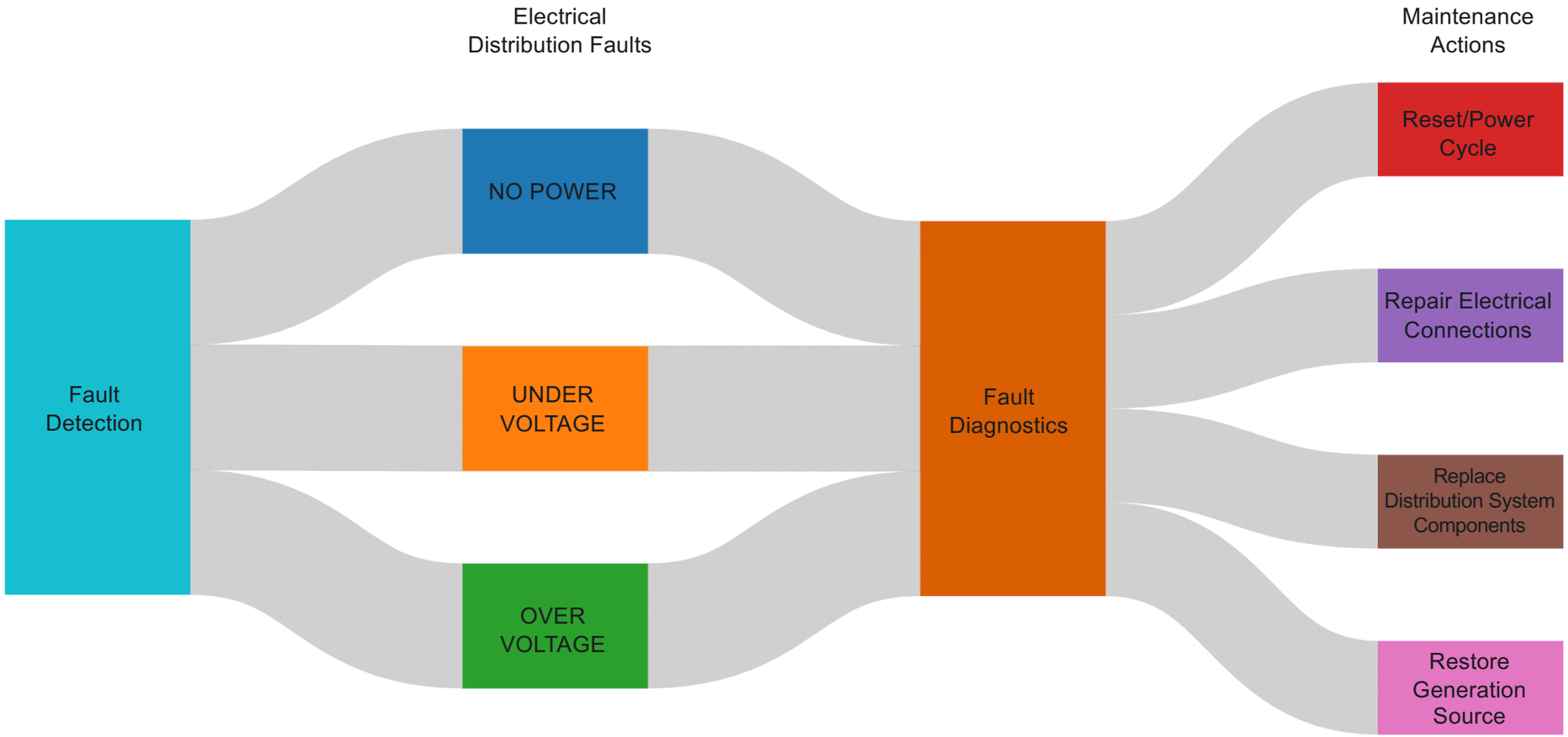
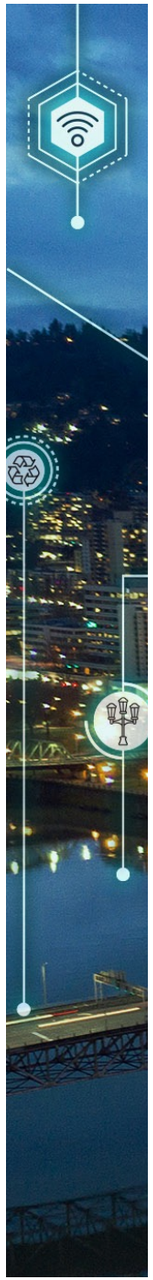
Electrical Distribution Faults & Maintenance Actions





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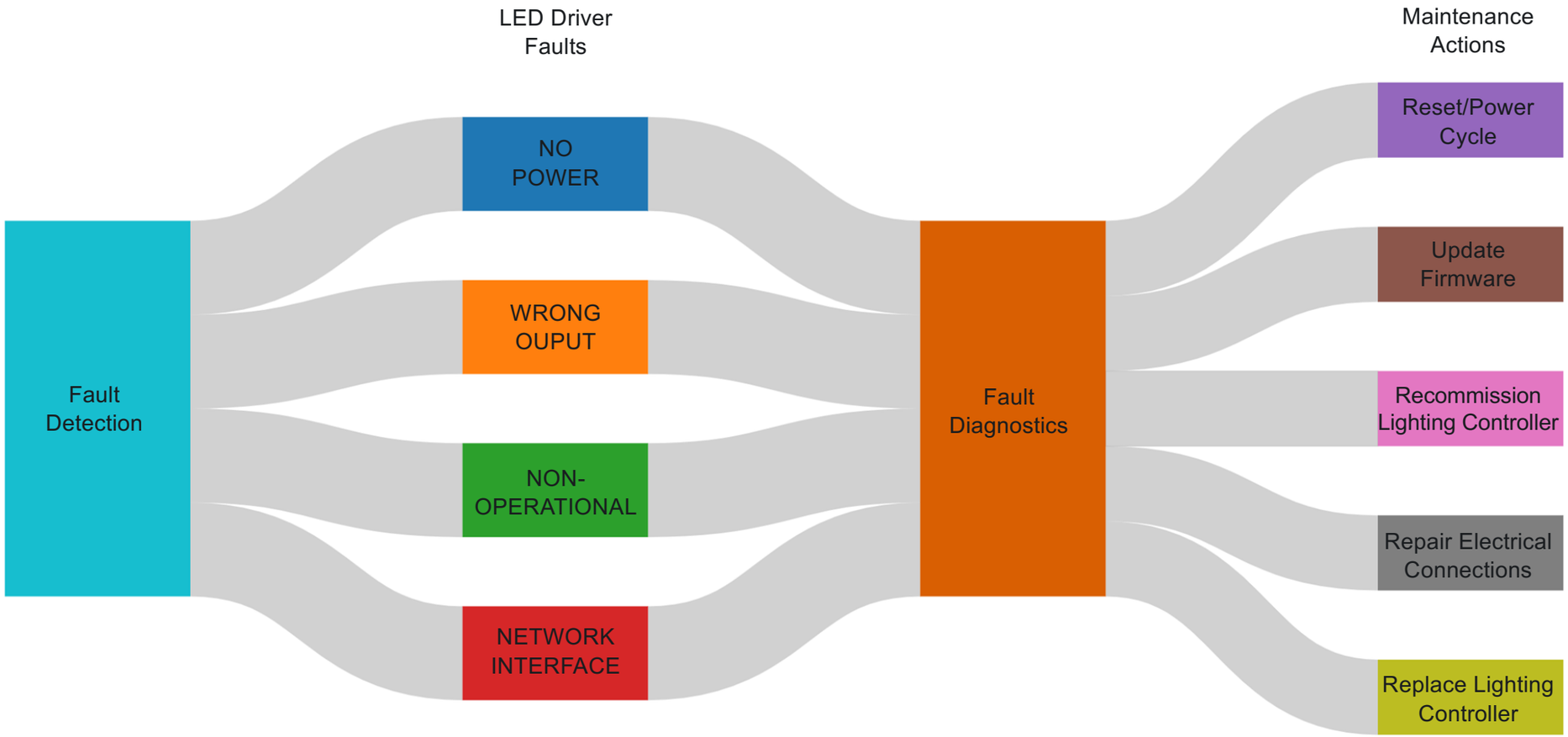
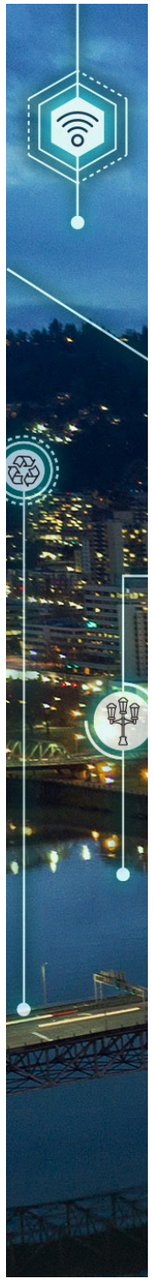
LED Driver Faults & Maintenance Actions





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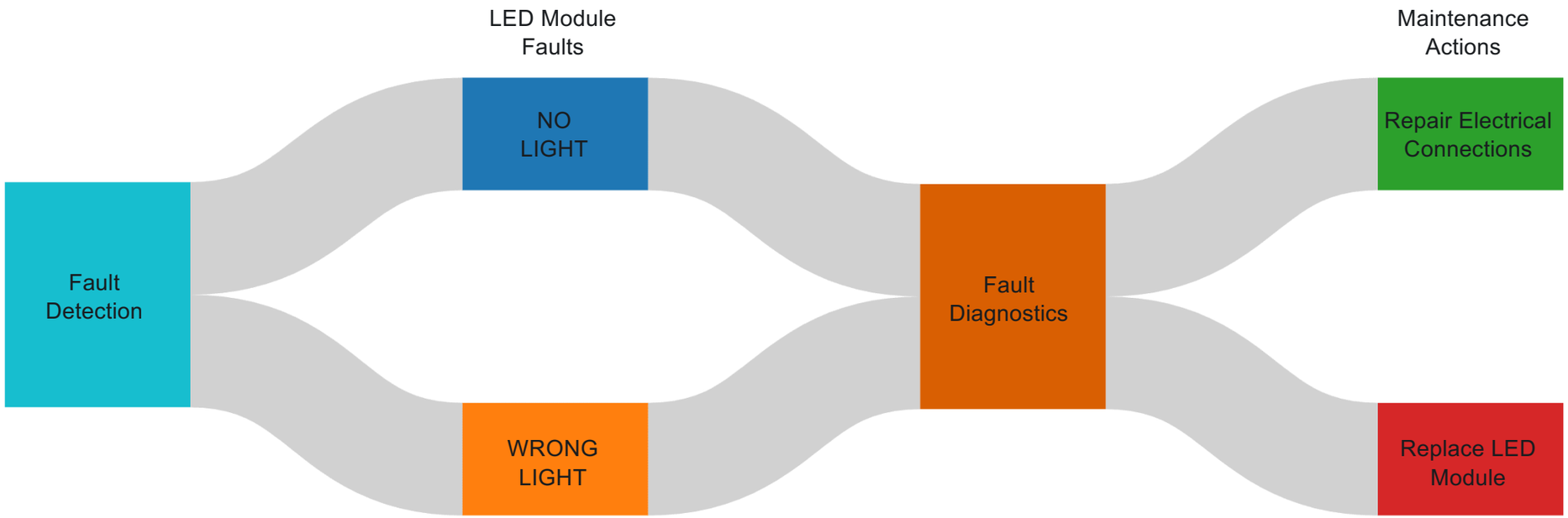
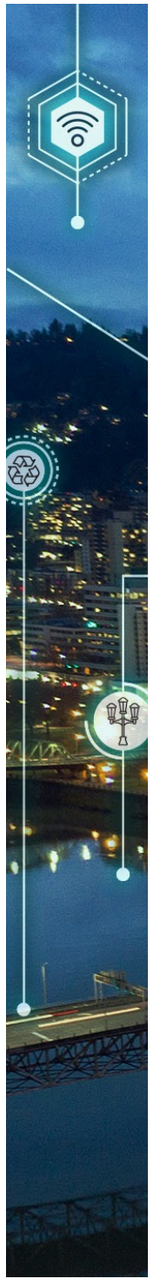
LED Module Faults & Maintenance Actions





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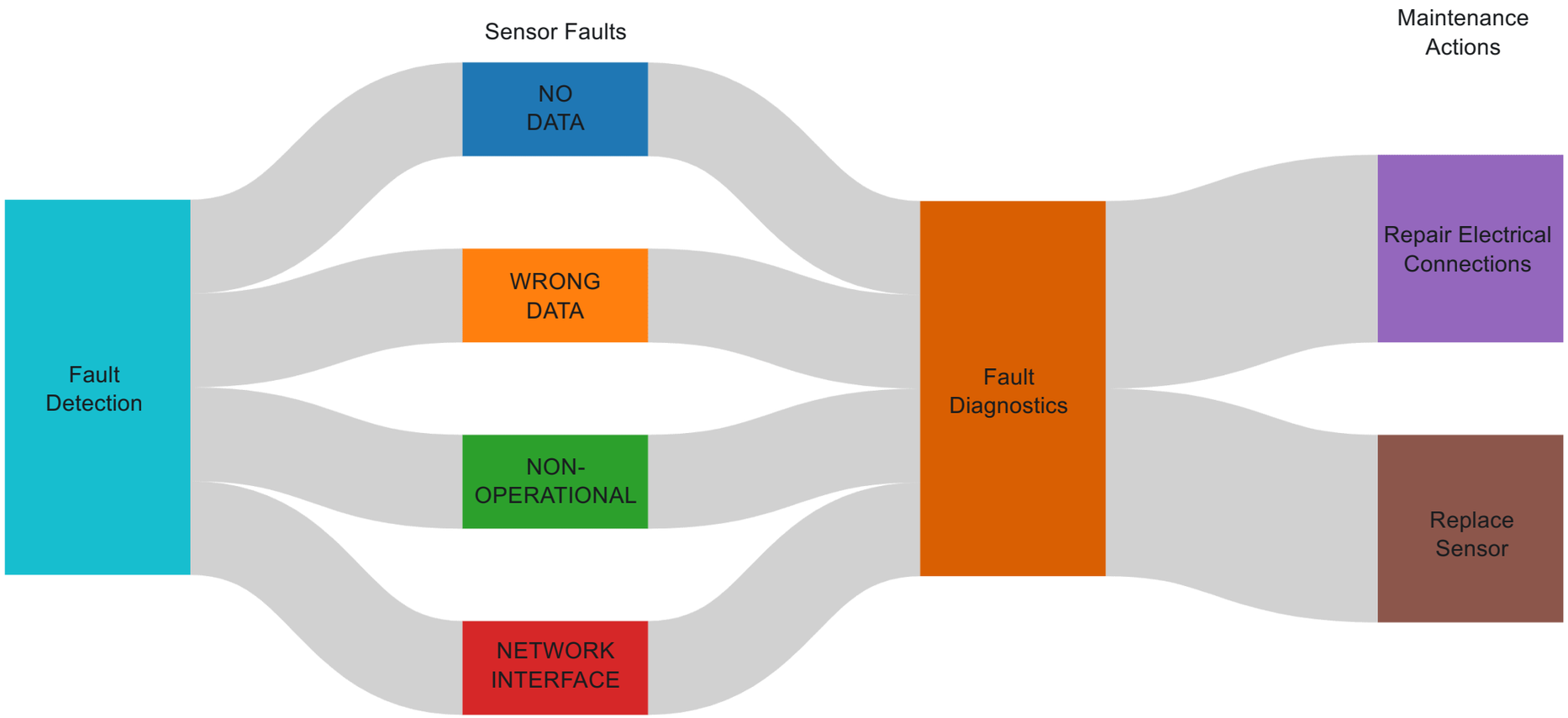
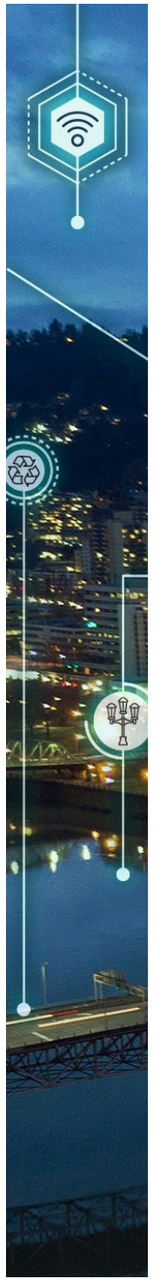
Sensor Faults & Maintenance Actions





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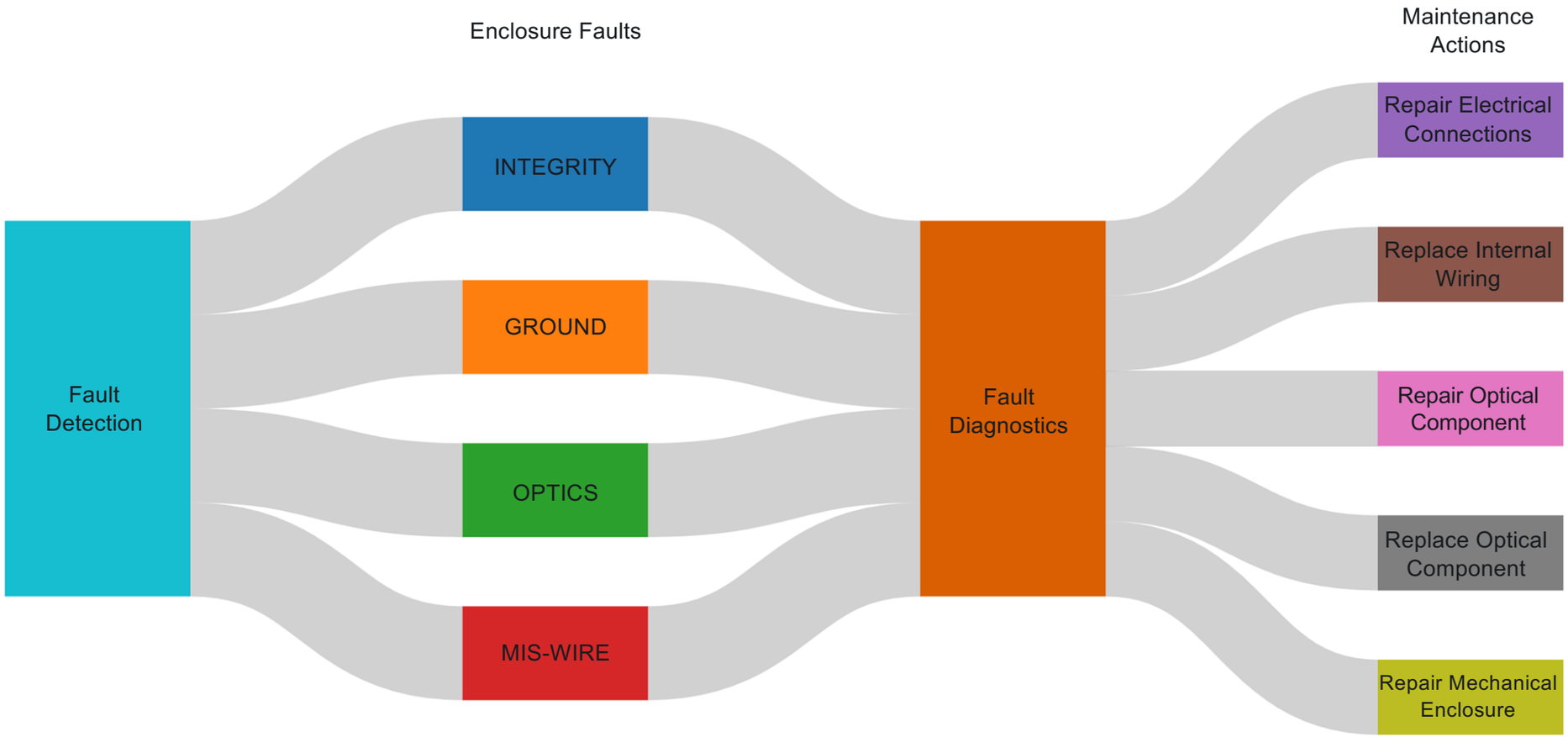
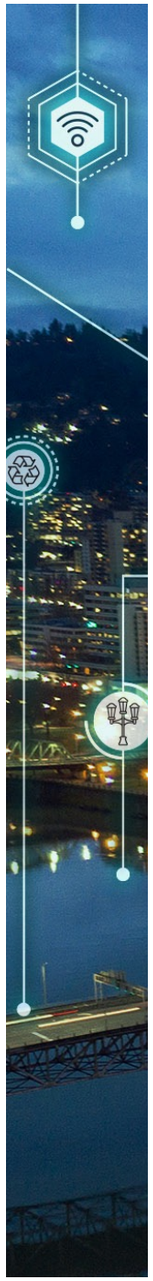
Enclosure Faults & Maintenance Actions





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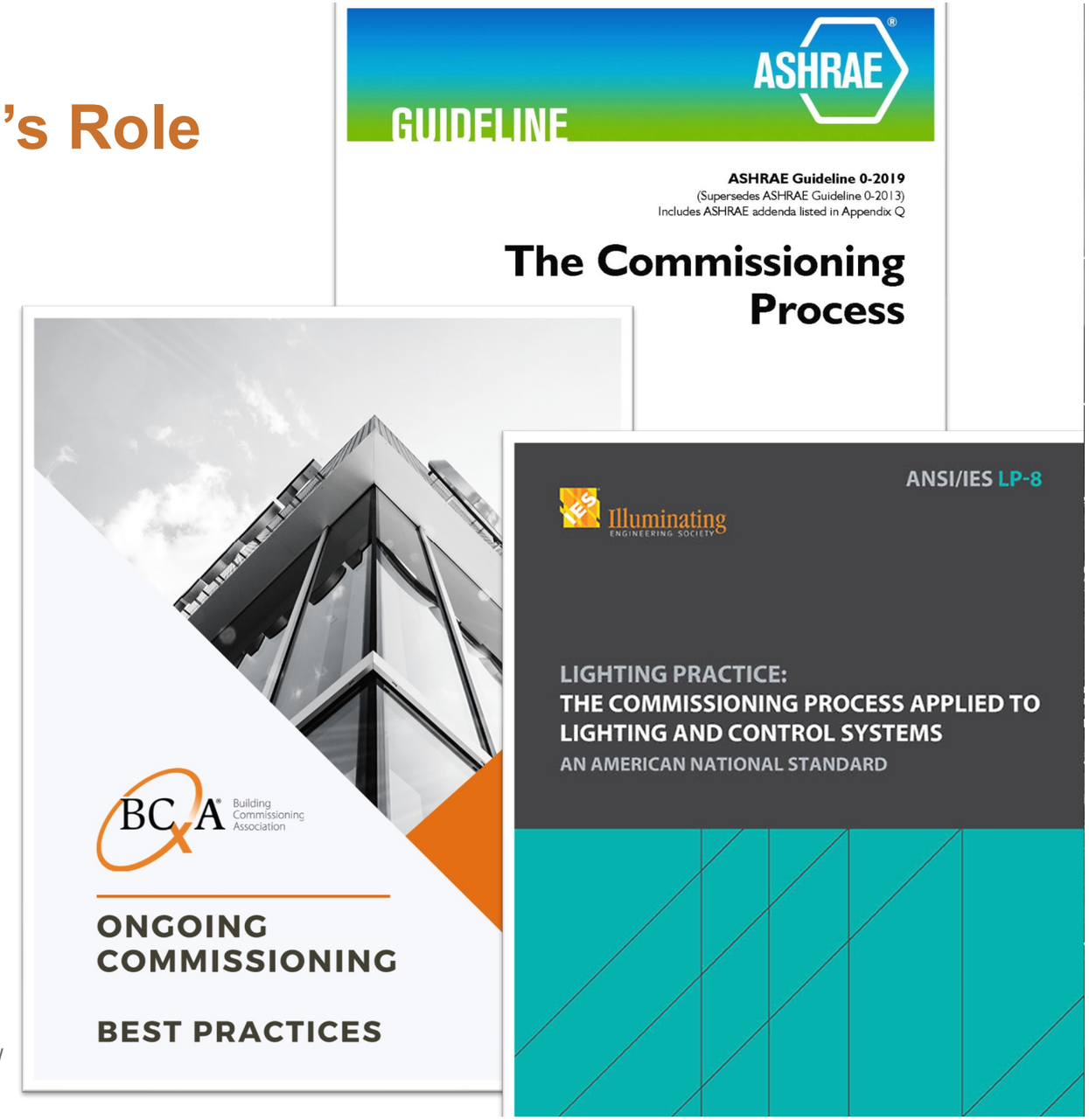
BCxA Building Commissioning Association

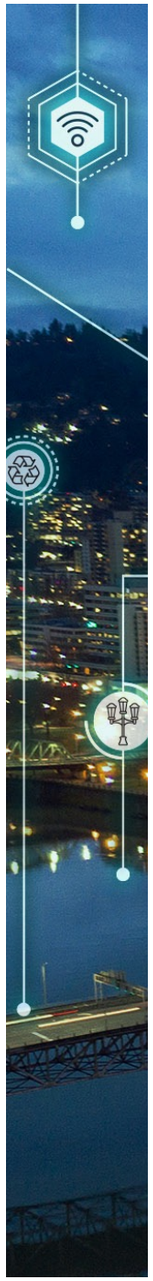
Commissioning's Role

- Commissioning
  = quality process
  - Prevent issues
  - Set up for success
  - Verify performance

COMMISSIONING IS NOT STARTUP!

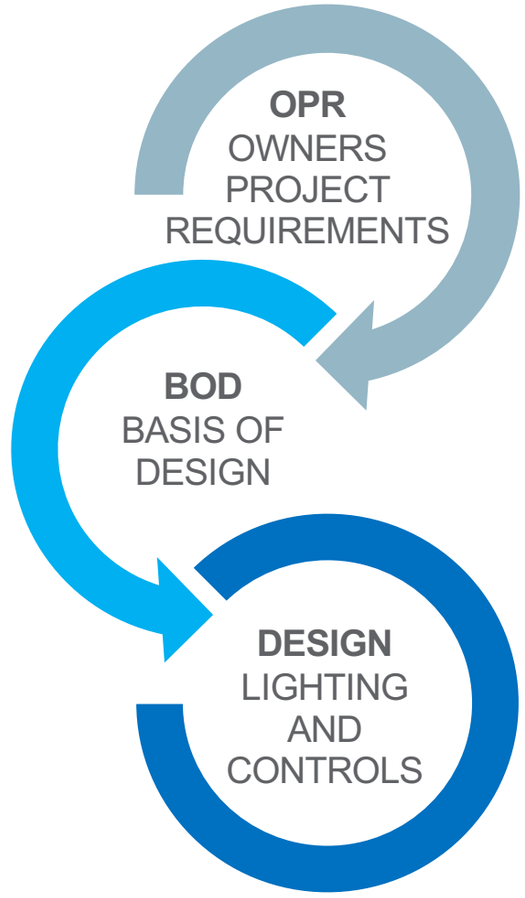
Download Commissioning Best Practices at https://www.bcxa.org/





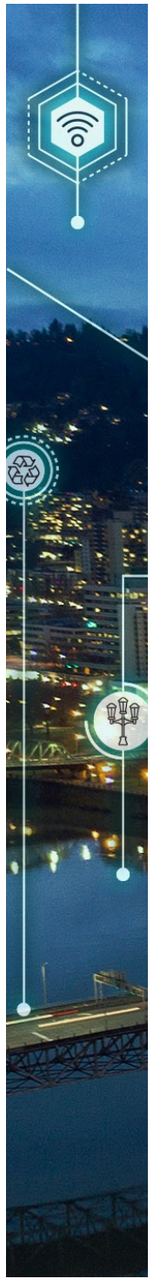
FDD: Setup is crucial

- Owner's Project Requirements (OPR)
  - Requirements for FDD
  - Lighting control system vendor
  - Networked lighting system
  - Point naming convention
- Basis of Design (BOD)
  - Ownership of OPR goals
- Design
  - Specifications & Diagrams
    - ✓ Manufacturer
    - ✓ Naming convention
    - ✓ System architecture
    - ✓ Sequence of Operation (SOO)



Functional Testing essential for Automated FDD

- Functional Testing
  = performance verification
  - During construction
  - Verify automated faults
    - ✓ Prevent GIGO
    - ✓ Validate accurate reporting
- Ongoing Commissioning (OCx)
  - More than Monitoring-based Cx (MBCx)
  - Automated Testing (Analytics)
    - ✓ point naming convention (semantic tagging)
    - ✓ [BUILDING NAME]_[room number]_[device]_[##]
  - Verification periodically repeated
    - ✓ Software, programming or API updates may cause analytics failures



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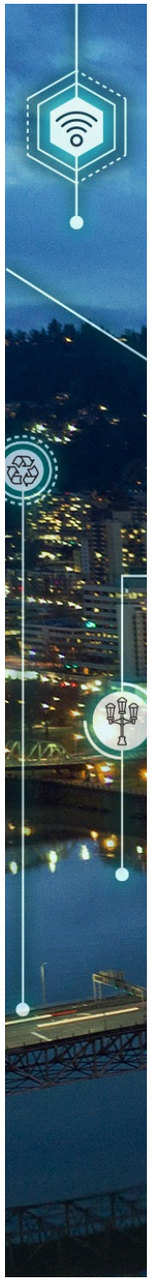
Questions for you

- What is the potential for lighting system AFDD in different phases of development?
  - Cost savings, time savings, energy savings, lighting service?
  - Configuration, Commissioning, Operation and Maintenance?
- What is currently limiting the realization of lighting system AFDD potential?
  - Commercially available product capabilities?
  - 3rd party software tool capabilities?
  - Industry standards?
- What is the need/opportunity for industry standards to accelerate the adoption of lighting system AFDD?
  - Similar to the HVAC industry?
  - Different from the HVAC industry?



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Questions for us?

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