Towards Carbon Neutrality: A Reference Architecture using CIP Energy

Chatrapathi GV
Technical Director
Utthunga GmbH

Jegajith PT
Technical Director
Utthunga Technologies

Nithin SP
Business Director
Utthunga Technologies

Presented at the ODVA
2025 Industry Conference & 23rd Annual Meeting
March 19, 2025
Clearwater Beach, Florida, USA

Abstract

Achieving carbon neutrality in industrial automation demands a holistic approach that integrates cutting-edge technologies and efficient energy management practices. This paper examines the essential automation requirements for attaining carbon neutrality, the current challenges in adopting CIP Energy[1], and a proposed reference architecture to address these issues.

To reach carbon neutrality, industrial automation systems must incorporate real-time energy monitoring, dynamic demand-response capabilities, and energy optimization algorithms. These systems should seamlessly integrate renewable energy sources, manage energy storage, and optimize energy consumption across all processes. Additionally, implementing predictive maintenance can minimize energy waste and enhance overall efficiency. CIP Energy offers fundamental building blocks for such solutions, meeting most of the necessary requirements.

However, implementing these solutions is not without challenges. The limited portfolio of devices supporting CIP Energy, the scarcity of compatible software applications, and the lack of knowledge and training among system designers, automation engineers, and end users pose significant obstacles.

To overcome these challenges, we propose a straightforward reference architecture that assumes partial to full CIP Energy implementation at the device level. This architecture outlines how to build energy-aware and dynamic demand-response capabilities at each layer, based on the degree of CIP Energy implementation, including workarounds to address gaps. It also discusses scaling the solution for larger implementations and cross-functional integration. The objective is to encourage the adoption of CIP Energy in devices and other OEM software, and to solidify the architecture through ODVA, potentially including necessary upgrades to the CIP Energy specification.

Definition of terms

CIP – Common Industrial Protocol
EMS – Energy Management System
OPC UA – Open Platform Communications Unified Architecture
PLC – Programmable Logic Controller
DCS – Distributed Control System
SCADA – Supervisory Control and Data Acquisition
MES – Manufacturing Execution System
ERP – Enterprise Resource Planning
SCM – Supply Chain Management
KPI – Key Performance Indicator
Scope 1 Emissions - Direct emissions from sources owned or controlled by the organization.
Scope 2 Emissions - Indirect emissions from the generation of purchased electricity, steam, heat, or cooling consumed by the organization.
Scope 3 Emissions - All other indirect emissions that occur in the value chain of the organization, including both upstream and downstream activities.

Table of Contents

1. Introduction

a. Carbon Neutrality

What?
Carbon neutrality for any industrial entity means balancing the amount of CO_2 produced with an equivalent amount removed from the atmosphere to achieve net zero emissions.

Why?
Achieving carbon neutrality is crucial for industries to mitigate climate change and comply with increasingly stringent regulations. It enhances economic benefits through cost savings and opens new market opportunities in the green economy. Additionally, it boosts a company's reputation, attracting environmentally conscious consumers and investors. By reducing reliance on fossil fuels and adopting sustainable practices, industries ensure long-term viability and resilience against future challenges. Overall, net-zero emissions represent a strategic move for industries to remain competitive, sustainable, and responsible in the face of global environmental and economic shifts.

How?
Industries can achieve carbon neutrality by implementing a range of essential strategies. These include optimizing performance through advanced technologies to enhance efficiency and reduce waste. Transitioning to renewable energy sources, such as solar and wind, helps lower carbon emissions. Measuring and tracking emissions across all scopes is crucial for setting and achieving targets. Decarbonizing supply chains involves collaborating with suppliers to adopt sustainable practices. Investing in low-carbon technologies, like carbon capture and green hydrogen, is vital for long-term sustainability. Leveraging financial incentives, such as green bonds and government grants, provides necessary funding for these initiatives.

Industrial automation and digitization technologies can significantly contribute to executing these strategies. CIP Energy offers fundamental building blocks for such solutions.

b. Challenges

The limited portfolio of devices supporting CIP Energy, the scarcity of compatible software applications, and the lack of knowledge and training among system designers, automation engineers, and end users pose significant challenges. Currently, only a small number of devices support CIP Energy standards, which restricts the ability to fully implement energy-aware systems and complicates the integration of non-compliant devices. Additionally, few software applications currently support CIP Energy, making it difficult to manage and optimize energy usage effectively. Existing software may not easily integrate with CIP Energy data, requiring custom development or middleware solutions. Furthermore, system designers, automation engineers, and end users often lack understanding of CIP Energy standards and their benefits. Insufficient training programs exacerbate this issue, leading to improper implementation and underutilization of CIP Energy capabilities.

2. Reference Architecture

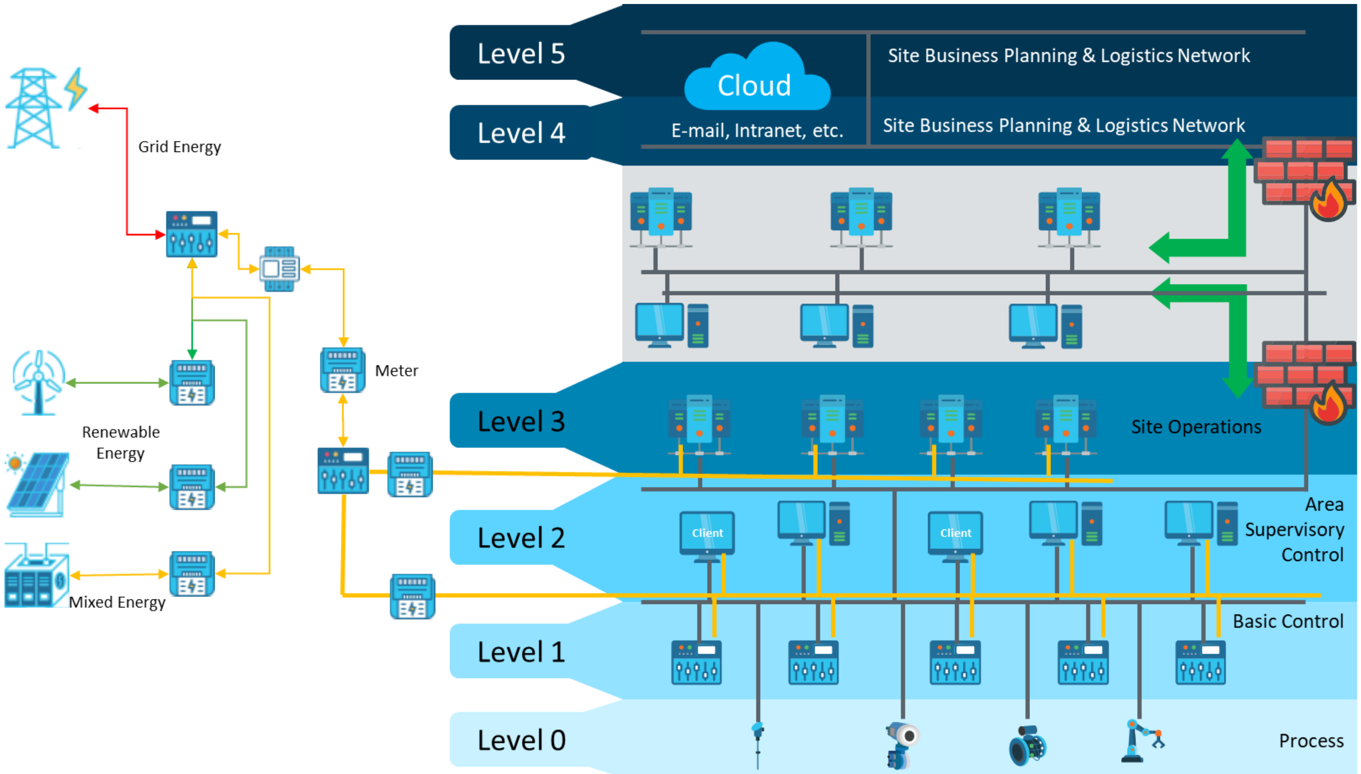

Figure 1: Energy Integration

a. Scope

This reference architecture focuses on data acquisition and data integration into the rest of the systems at lower layers. Additionally, this architecture explores how this data can be utilized to build energy awareness and respond to the dynamic demands. At device and control level, a partial or full implementation of CIP Energy is assumed. This further extends the scope to provide work arounds in the cases of partial implementation of CIP Energy.

b. Approach

The reference architecture leverages existing industrial automation architecture to integrate functionalities required to build energy awareness, execute optimization strategies, integrate renewable and regenerative energy sources and to respond dynamically to the energy demand. At each layer, it specifies which CIP Energy features to use and identifies independent software components and functionalities to be developed and integrated.

c. CIP Energy – Quick Overview

CIP Energy includes a family of objects and services that enable scalable implementation, from basic energy awareness to advanced energy control functions. These objects help in monitoring, controlling, and optimizing energy usage, as well as supporting dynamic demand-response.

The Objects

1. Base Energy Object: Provides fundamental energy information like energy odometer, type of energy, measurement methods, etc. Also, provides functionalities and services to accommodate aggregate multiple Base Energy Objects, or to act as a proxy for devices that don't have

measurement capabilities, or to configure fixed energy transfer rates. Integrating regenerative features of the devices is straight forward using the Generated Energy Odometer attribute.

2. Electrical Energy Object: Manages electrical energy information. Each instance of this object is associated with a Base Energy Object. The information further extends to reactive energy, line specific current & voltage for 3 phase supply etc.

3. Non-Electrical Energy Object: Handles non-electrical energy information. Each instance of this object is associated with a Base Energy Object. Supports different types of energy resource types like natural gas, compressed air, coal etc., with corresponding engineering units.

4. Power Management Object: Focuses on overall power management. Provides services to do scheduled transitioning of the devices into energy saving and operational states.

5. Power Curtailment Object: Focuses on managing the energy consumption and power levels. Provides services to create customized power consumption levels and to transit the devices and system between the levels. These services are utilized by energy management systems and applications to respond dynamically as per the supply and demand of energy.

d. Architecture

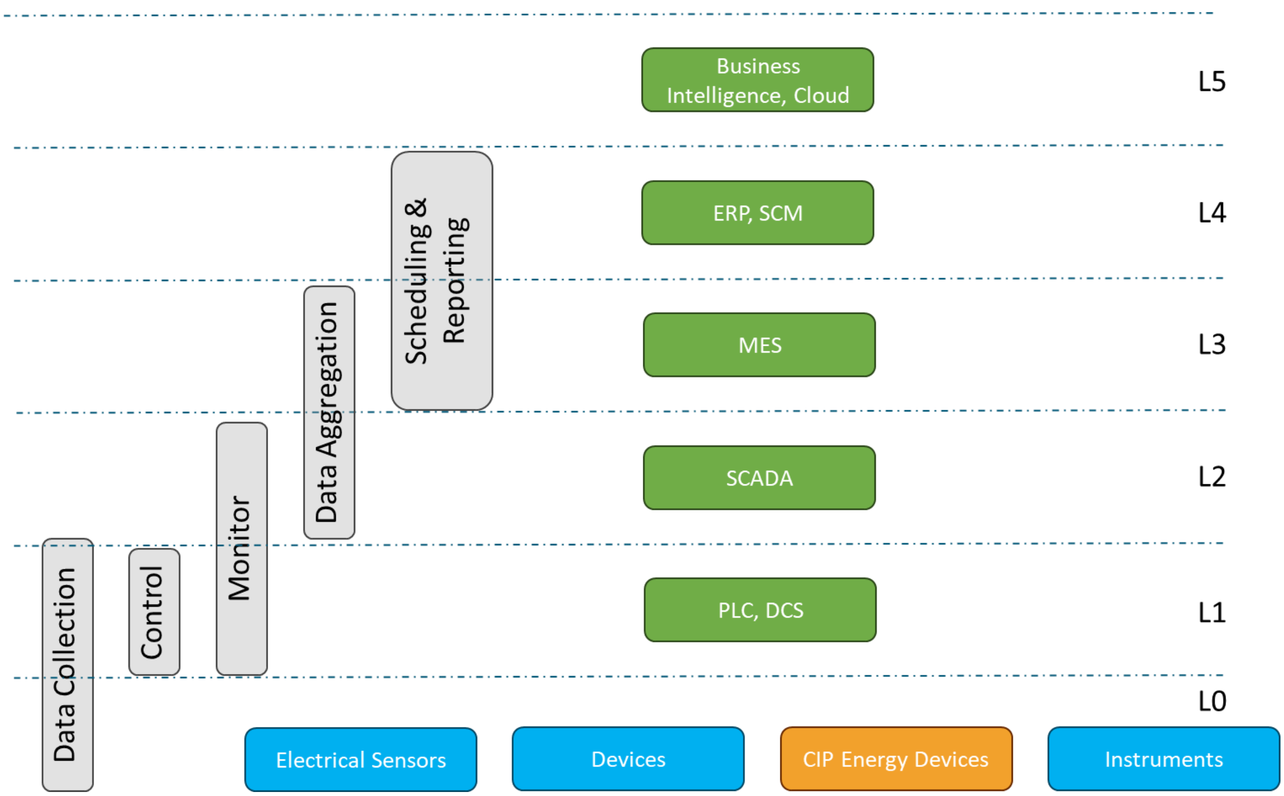

Figure 2: Automation Layers

i. Data Collection for Energy Awareness

From an energy awareness perspective a broad categorization of the devices from data collection consists of devices with a CIP Energy implementation and devices without a CIP energy implementation

Both categories are integral to the process. In addition to this, outside the scope of the process, there are external electrical sensors and other instruments to measure any regenerative energy.

CIP Energy devices give access to a wide variety of data as per the specification. Data such as the type of energy (Electrical and Non-Electrical), consumed energy, generated energy, net energy, whether the energy is measured, or fixed rate or derived or aggregated are key pieces of information.

Controllers that implement CIP Energy aggregate energy data from other devices. For each device, a Base Energy Object instance is created with appropriate Base Energy Object Capabilities and Energy Transfer Rate. A Base Energy Object to aggregate data from all such devices is created and configured. This includes Other Electrical sensors and instruments in the network.

For the controllers not having such capability, a software program using the CIP Energy object model is being proposed. Electrical sensors and other instruments share the energy data with the controllers into mapped viables, or with the software program.

The data model and data collection approaches for these cases explained in detail below.

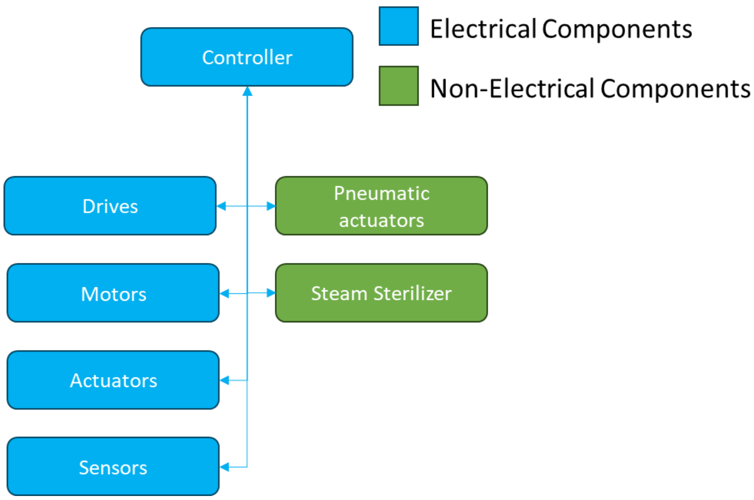

Figure 3: Components in a Packing Machine

Consider a packing machine that has both electrical and non-electrical components. Drives, Motors, Actuators and Sensors consume electrical energy. Some motors have regenerative capabilities to recover energy during deceleration. Pneumatic actuators, steam sterilizers or sealing equipment consume nonelectrical energy like compressed air and steam. The data collection using CIP Energy is carried out by multiple Base energy objects based on a number of types of energy sources. In this example, there are three types of energies being used: Electrical, Compressed Air and Steam.

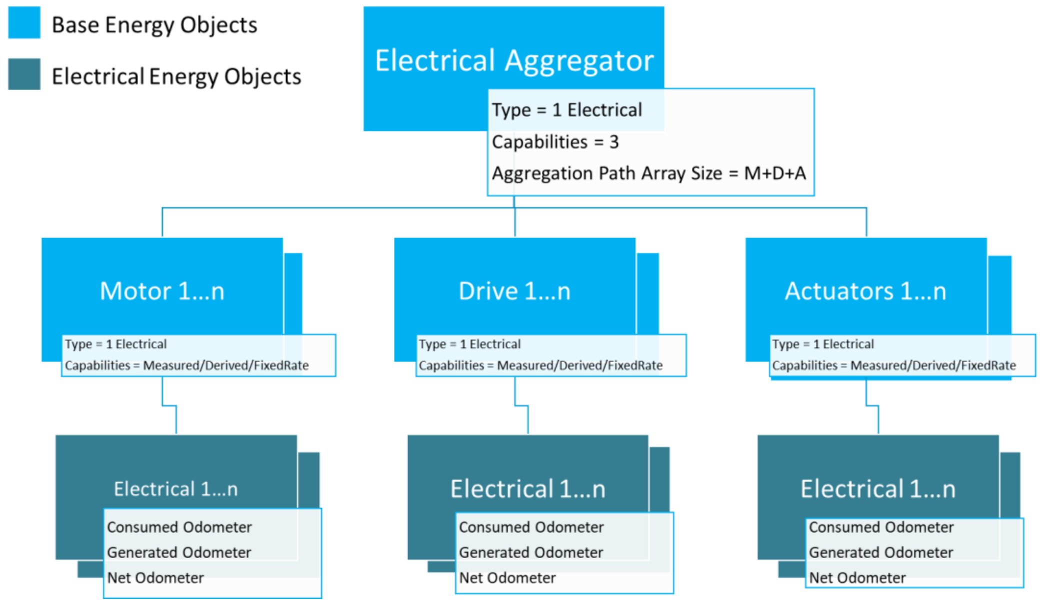

Figure 4: Aggregation of Electrical Energy in a Packing Machine

For electrical energy, a Base Energy Object aggregates the odometers from individual Base Energy Object instances. Each of the Base Energy Objects is associated with an Electrical Energy Object that provides actual odometer values. The Generated Energy Odometer accounts for any regenerative energy at each component level.

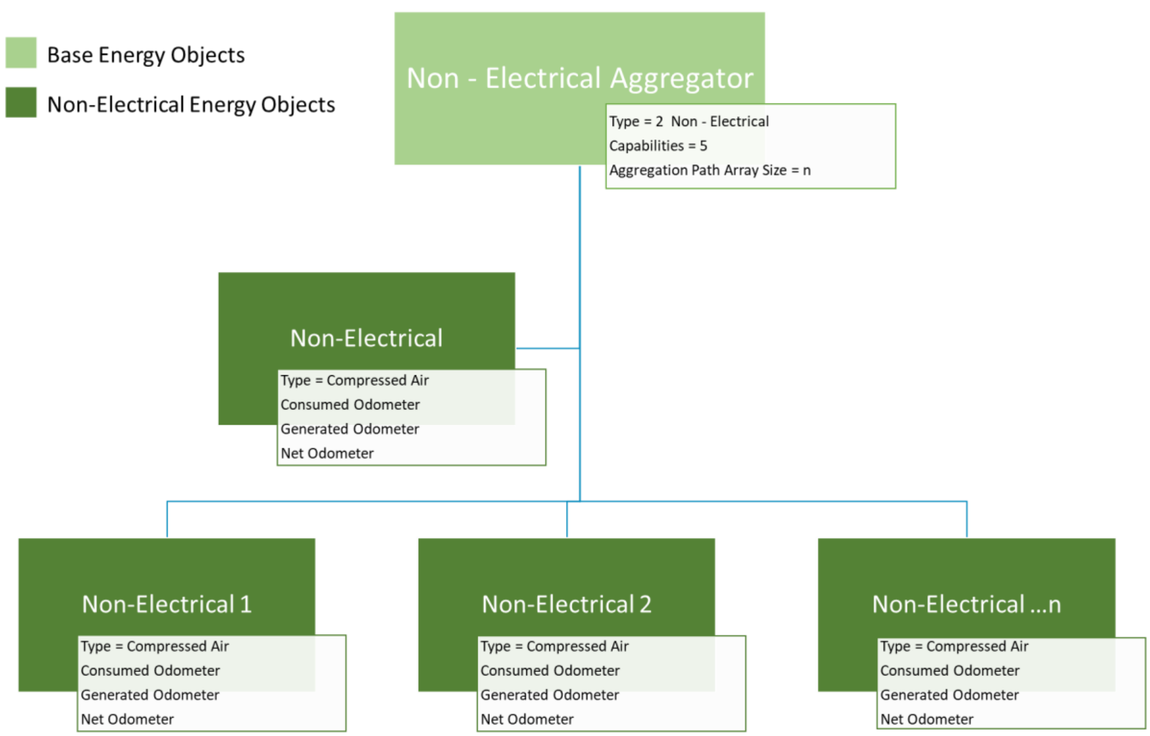

Figure 5: Aggregation of Non-Electrical Energy (Compressed Air) in a Packing Machine

For each type of non-electrical energy, a Base Energy Object aggregates the odometers from individual type specific Non-Electrical Energy Objects. Though there is an association with Base Energy Object for each of the Non-Electrical Energy Objects, for the purposes of aggregation it is not relevant. Above and below examples show nonelectrical energy aggregation for compressed air and steam.

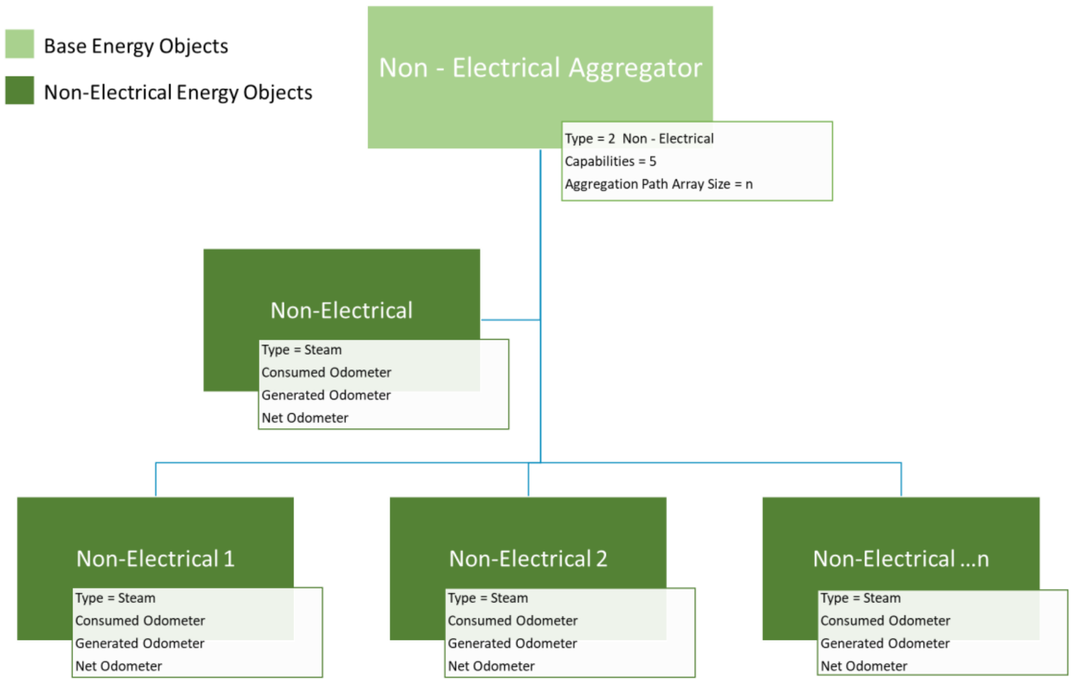

Figure 6: Aggregation of Non-Electrical Energy (Steam) in a Packing Machine

Proposed Architecture for a Data Collection Software Application

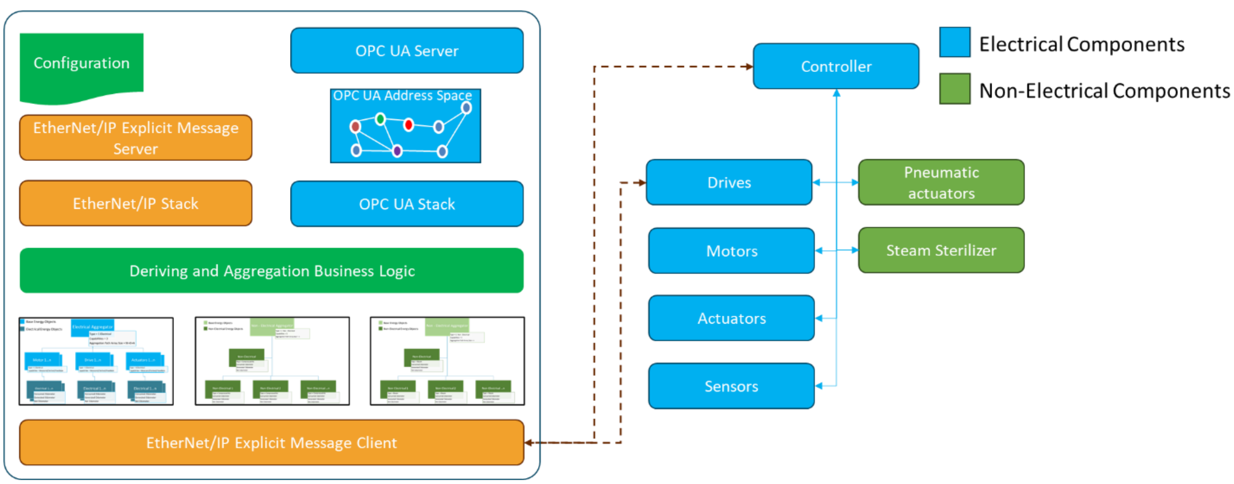

Figure 7: Proposed Architecture of a Data Collection Software Application

An architecture is being proposed for a Data Collection Software Application as shown in the above picture. The following are the requirements for the software application.

1. Collect the aggregated or individual data for energy awareness from CIP Energy devices.

2. Support for electrical and nonelectrical devices/sources.
3. Ability to configure the following types of data sources.
    a. CIP Energy
    b. Derived and Fixed Rate virtual sources (Electrical and Nonelectrical)
    c. Controller parameters (For cases where there is no CIP Energy implemented on Controller but can read energy data from devices mapped to controller variables)
4. Ability to run as an independent application on basic process control level and supervisory control level infrastructure. Basic process control level includes sensors, actuators, and PLCs that directly manage equipment. Supervisory control level includes systems like SCADA that monitor and control multiple basic process control level systems. Supervisory control level provides an overview of the entire process, allowing operators to make informed decisions based on real-time data collected from various sensors and devices
5. Ability to provide aggregated data to other instances of the same application.
6. Ability to provide aggregated data to other EtherNet/IP Client applications as per CIP Energy model.
7. Ability to provide aggregated data to other OPC UA Client applications as per Energy Consumption Management information model.
8. Optionally, interfaces like DNP3[2], IEC61850[3], to integrate with other EMS systems and technologies can be supported. For example, OpenEMS[4]
9. Consume initial configuration to create necessary data model based on CIP Energy.
10. Additional configuration required for Deriving and Aggregation business logic.

An application that meets these requirements solves several different use cases. Limitations such as some devices lacking CIP Energy implementation and others having only partial CIP Energy features at the field or control level can be addressed. Additionally, other limitations such as access restrictions to existing field-level infrastructure, constraints on modifying or updating control-level programs, and security-related access restrictions can be addressed while still maintaining a reasonable degree of energy awareness. The degree of accuracy varies depending on several factors and limitations discussed above. Also, the configuration data such as Fixed Rates, implementation of Deriving and Aggregation Business Logic affect the accuracy of the energy awareness data.

ii. Control for Optimization and for Dynamic Demand - Response

Optimizing field level energy consumption involves different approaches at control level. Optimizing setpoints, sequencing of process steps to reduce energy consumption, reducing idle power consumption, pausing or switching off the equipment are some of the steps.

With CIP Energy implemented, some of these steps are executed by calling services of Power Management Object. This includes pausing the device or sending it into sleep mode and resuming it based on scheduled time.

For the cases where CIP Energy is either partially implemented or not implemented, additional logic at the controller level is used to carryout similar activities. For example, sending a drive into idle state by setting the Speed Control attribute of an AC/DC Drive object.

Dynamic demand response involves adjusting energy consumption in real time based on grid conditions like peak demand periods, congestion, frequency deviations, supply fluctuations due to renewable energy integration, dynamic prices etc.

At the control level, developing and executing control algorithms to adjust energy consumption, dynamically adjusting setpoints within the thresholds of process quality, and sleeping or pausing of sub system components are some of the steps to achieve dynamic demand response.

With CIP Energy implemented, most of these steps are executed by calling services of the Power Curtailment Object. The control algorithm determines what Curtailment Level to pass when calling the Go_To_Level service.

For the cases where CIP Energy is either partially implemented or not implemented, a software component using Power Curtailment Object model is being proposed. The following are the high-level requirements for the software component.

1. Ability to create curtailment levels for the system or sub systems. For example, a packing machine.
2. Ability to configure individual component behaviors at each level.
3. Ability to switch between the levels.
4. Ability to configure transition sequences between levels.

These requirements can be part of the already proposed software application. The architecture of the application proposed is shown below. Additional configuration for curtailment levels per component and transition sequences are stored. Additional business logic to apply the levels based on current conditions is implemented.

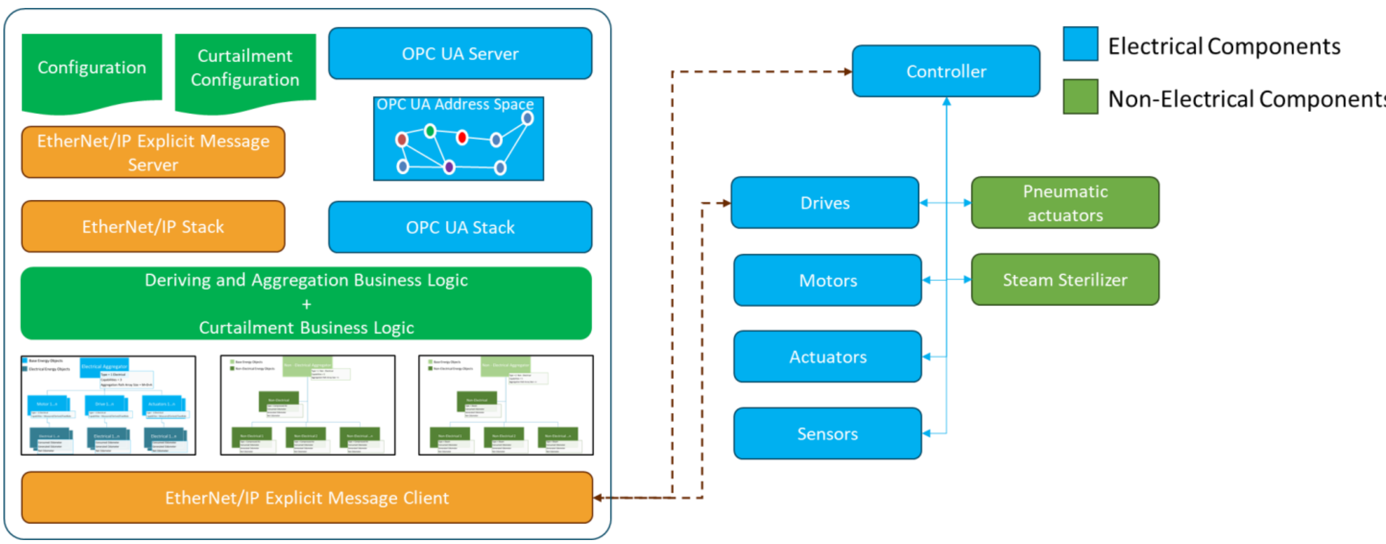

Figure 8: Updated Architecture with Curtailment

iii. Supervisory control and above

From Supervisory control and above layers the approaches and strategies differ based on specific industry, different types of energy sources, varying availability based on external conditions like weather, varying pricing models, peak loads, overall organizational energy KPIs etc.

There are several EMS (Energy Management Systems) available. These systems support real time energy data collection, monitoring and reporting. They conduct energy audits, analyze the data to create benchmarking and optimization strategies including predictive maintenance, dynamic demand response and cost optimization.

However, having access to accurate and real time energy data along with means to control the energy consumption at field level provides a strong requirement for any EMS systems for fulfilling its responsibilities.

Having multiple instances of the proposed software operating at the lower levels meets such requirements. Most of the EMS support several standard protocols for integrating with the automation systems including OPC UA, IEC61850, DNP3, MODBUS etc. Integrating the proposed software instances with the EMS makes it possible to meet its own requirements in achieving energy KPIs at organizational level.

3. Recommendations

a. Integration of carbon cost

The recommendation is to design and integrate capabilities to adjust carbon cost dynamically based on switching of energy sources. Even though this may be available at above layers, having this information at supervisory control level and below is critical in building energy aware and carbon conscious sub systems.

To integrate carbon cost into CIP Energy objects, the existing CIP Energy framework can be enhanced by adding specific attributes and services that track carbon emissions associated with energy consumption.

New Attributes: Introduce new attributes within the CIP Energy objects to record carbon emissions data. For example, Carbon Emission Rate (mass/unit of energy) and Total Carbon Emissions (mass). Update the existing CIP Energy objects, such as the Base Energy Object, Electrical Energy Object, and Non-Electrical Energy Object, to include these new attributes. This ensures that carbon emissions data is available alongside energy consumption data.

New Behavior: Develop logic within the CIP Energy objects to calculate carbon emissions based on energy consumption and the type of energy source used. For instance, if renewable energy sources are used, the Carbon Emission Rate might be lower compared to non-renewable sources. Enable the CIP Energy objects to dynamically adjust carbon emissions calculations based on real-time switching of energy sources. This can be achieved by incorporating logic that updates the Carbon Emission Rate attribute whenever there is a change in the energy source.

Integration with Higher Layers: Ensure that the carbon emissions data collected at supervisory control level and below is integrated with higher layers of the automation system. This allows for comprehensive energy and carbon management across the entire organization.

By incorporating these enhancements, the CIP Energy objects can provide a more holistic view of energy consumption and its associated carbon footprint, enabling more effective energy and carbon management strategies.

b. Integration of emission scope

Integrating Scope 1, and 2 emissions with CIP Energy helps in meeting regulatory compliance, and sustainability goals.

Introduce new attributes to record scoped emissions. For example, Direct Emission Rate (mass/unit of fuel), Total Direct Emissions (mass), Indirect Emission Rate and Total Indirect Emissions. Alternatively, a much simpler solution would be to add a single attribute Emission Scope (1, 2 or 3) to the CIP Energy Objects.

c. Supporting new sources

There are several non-electrical energy sources like solar thermal, hydrogen, biomass, geothermal etc., not supported by CIP Energy. Update Resource Type attribute of Non-Electrical Energy Object to support such sources. Current workaround is to use Vendor Specific range to support any new types.

d. Supporting sub system or machine-level KPIs

Integrating subsystem or machine-level KPIs for energy consumption, carbon emissions, and carbon costs into the CIP Energy framework offers benefits in terms of better energy management, better carbon cost management and helps in monitoring and meeting of sustainability goals in a much efficient way. This recommendation is applicable to control level and above.

New Attributes: Introduce new attributes within the CIP Energy objects to set KPI. For example, array of structure with members like KPI Type (Energy Consumption, Average Energy Consumption, Carbon Emissions, Scope 1 Emissions etc.,), KPI Evaluation Duration, KPI Limit, KPI Percentage and KPI Status (On Track, At Risk, Off Track etc.,). Update the existing CIP Energy objects, such as the Base Energy Object, Electrical Energy Object, or Non-Electrical Energy Object to include this new structure as an attribute.

New Behavior: Develop logic within the CIP Energy objects to monitor and update the attributes like KPI Percentage and KPI Status. For example, when a KPI for Average Energy Consumption is set to a machine controller, the rolling average is calculated based on KPI Evaluation Duration and corresponding KPI Percentage and KPI Status are updated.

4. Conclusion

Achieving carbon neutrality in industrial automation requires a comprehensive approach that integrates advanced technologies and effective energy management practices. While CIP Energy provides essential components for these solutions, significant challenges remain, including limited device support, software compatibility issues, and a lack of expertise among stakeholders. The proposed reference architecture addresses some of these challenges by outlining a scalable and integrative framework for implementing energy-aware and dynamic demand-response capabilities. This approach aims to promote the adoption of CIP Energy and enhance the overall efficiency and sustainability of industrial automation systems.

References

[1] ODVA, The CIP Networks Library, Volume 1: Common Industrial Protocol, Ann Arbor: ODVA, Inc., 2001-2024.
[2] https://www.dnp.org/About/Overview-of-DNP3-Protocol
[3] https://iec61850.dvl.iec.ch/
[4] https://openems.io/