Efficient Coupling Of Water and Energy Technologies for Smart Sustainable Cities

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Table of Contents

1. Purpose of the Document

This report provides a detailed description of the architecture and design involving hardware, software and communication technologies. In order to develop the design and architecture for the project, various requirements and usecases are considered from Deliverable 1.1 -report on the usecase specification and requirements. A formal software architecture view of the complete system is described, which is composed of the functional building blocks. These blocks include description of hardware and software binding, integrated real-time data provisioning, decision-making scenarios based on the data analysis and post-processing.

Based on the detailed analysis of the state-of-the-art, communication technologies available and the suitability of such technologies w.r.t the testbed are taken into account while design of the communication architecture suitable for real-time monitoring and controlling of hardware.

2. Architecture

Within the scope of the project, efficient coupling of water and energy technologies involves design of conceptual framework for intelligent energy management of critical infrastructures such as Sewage Treatment Plant (STP), Water Treatment Plant (WTP) and Street lighting system at Gyan Marg at Gujarat International Finance-Tec (GIFT) city. The "efficient coupling" is done by application of solar photovoltaic (PV) and battery storage unit used to power both water and energy technologies.

Several Sensors are connected in both STP and WTP. Multi-Function Meters (MFM) for monitoring Aeration Blower energy consumption, Dissolved Oxygen (DO) sensors along with battery support are of interest in the STP. The energy generation from solar photovoltaic system is also recorded using MFM meters. The option of automatic speed control of aeration blower will also be explored and implemented based on experimental results at lab scale. The measurements from DO sensor are recorded at regular time-intervals. The STP Battery charging and discharging dispatch signals from optimization algorithm will be sent and executed at STP. In the same way, the energy consumption of hypodosing pump and air compressor are recorded in the WTP and optimized similar to STP usecase. Streetlights are also supported by the battery system. The energy consumption of streetlights at Gyan Marg is recorded using streetlight controller application deployed by the manufacturer. The optimization and control of streetlights will be implemented as part of street lighting usecase.

2.1. Overall System View

The testbed comprises of STP, WTP & street light system at GIFT city. The overall system architectural view is presented in figure 1. The bottom layer (Layer-1) has all the hardware components such as Aeration blower, DO sensor, hypodosing pump, air compressor, street-lighting and batteries. Layer-2 has the software components to connect with the hardware. At this layer the device specific interfaces are implemented to connect with hardware. For example, Plant.STP monitors aeration blower demand, battery state of charge (SOC) and sensors values of dissolved oxygen level. Plant.WTP measures the energy consumption of hypodosing pumps, compressor and also measures battery's SOC. Plant.Streetlight monitors the energy consumption of street light and battery's SOC. Layer-3 receives the measured data as inputs and forwards it to Optimizer component for decision-making. The main business logic is embedded in this layer. It consists of business logic components respective to the plants (BusinessLogic.STP, BusinessLogic.WTP and BusinessLogic.StreetLight) and acts as a coordinator. The control signals are sent to field devices via the components at Layer-2. Decision making involves planning capabilities, which are provided by Layer-4. Layer-4 can be seen as purely software component layer where optimization and forecasting algorithms are implemented (Generation.Forecast, Demand.Forecast and Optimizer). The high level components help in balancing the battery usage between Plant.STP, Plant.WTP and Plant.Streetlight.

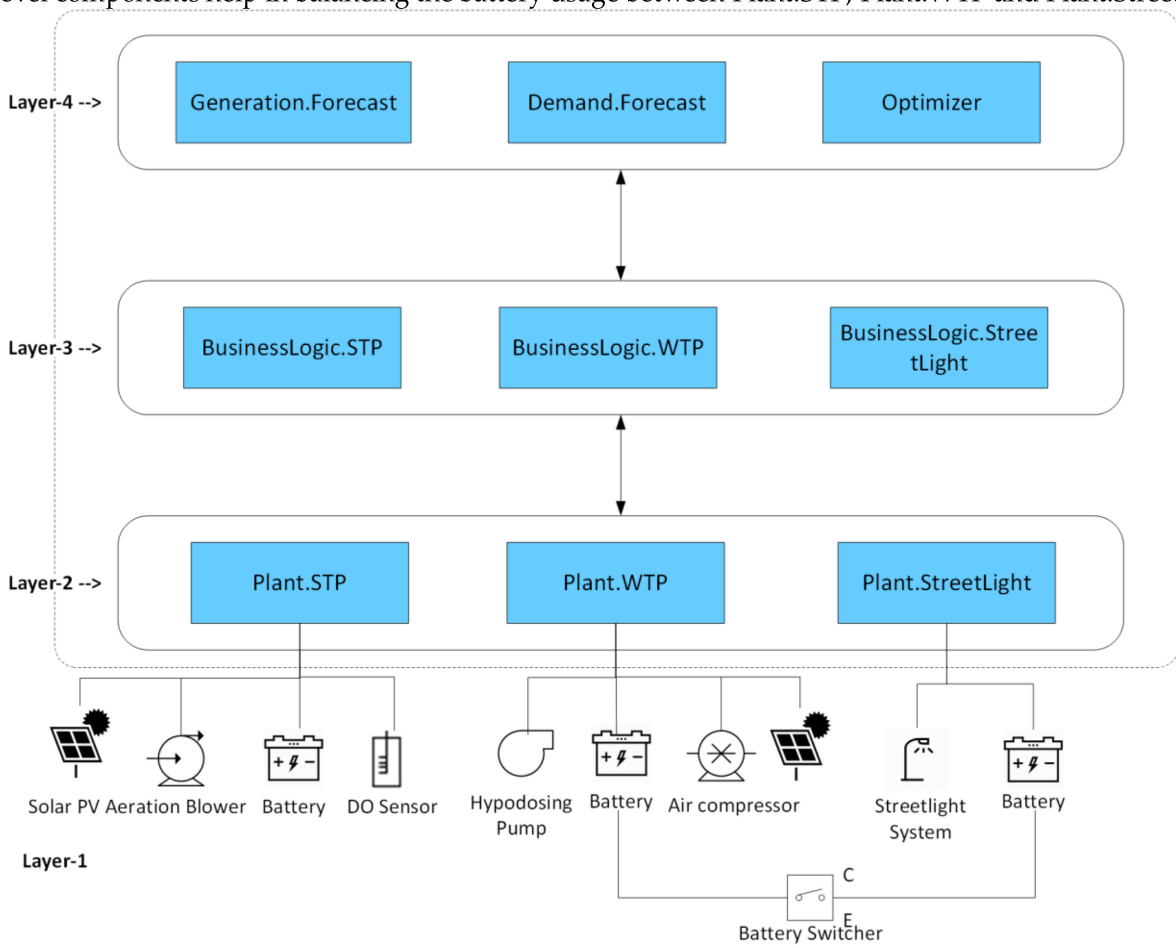

Fig. 1. System Architecture: Hardware-Software view

2.2 Communication View

The communication architectural view presented in figure 2 provides detail of the communication technologies used in the testbed. The communication channels and protocols are chosen based on various considerations such as distance between the plants, support to the protocol by different hardware and data latency requirements. Most of the installed hardware supports MODBUS or OPC UA communication protocol. By the time of drafting this document, streetlight controller and Battery-Switcher are being procured. After the deployment, appropriate protocols for lighting control and battery switch will be integrated. The energy consumption of Aeration blower, hypodosing pump and air compressors are measured and recorded using Multi-function Meters (MFMs). The data from MFMs is accessed using MODBUS protocol. The communication between batteries and plant level software components is also through OPC UA protocol. The data from DO sensor is accessed through SCADA software through OPC UA as well.

At Layer-2, the communication two or more protocols will be explored and supported. In the case of, layers between 2 and 4 OPC UA (OPC Unified Architecture) protocol will be followed.

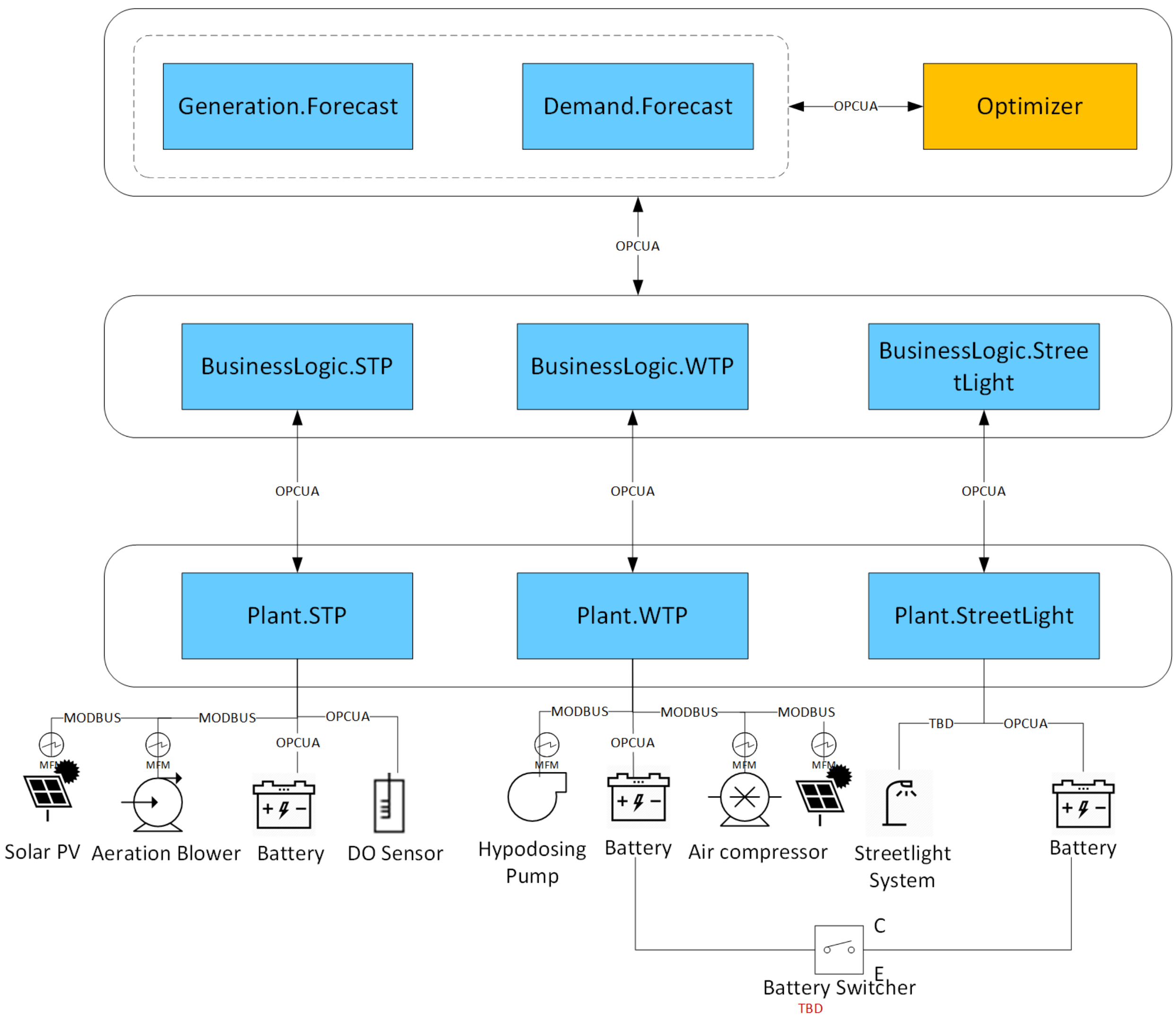

Fig. 2. Communication Protocol View

2.3 Hardware and Deployment View

The hardware and deployment view is presented in figure 3. The BusinessLogic, Optimization and forecasting components of the plants would require dedicated workstations. They would be installed at STP and WTP plants, shown as Workstation_STP and Workstation_WTP. Workstation_WTP monitors and controls both street light and WTP usecases and Workstation_STP is for STP usecase. These workstations represent the functionalities of Layer-3 and Layer-4. Since the feeder cables and other monitoring equipment of street lighting system is located close to WTP building, the controller components of street lighting system would also be deployed in WTP workstation. The Layer-2 level software components will be deployed on Raspberry Pis. Raspberry Pis and workstations would be connected through Ethernet/LAN cables.

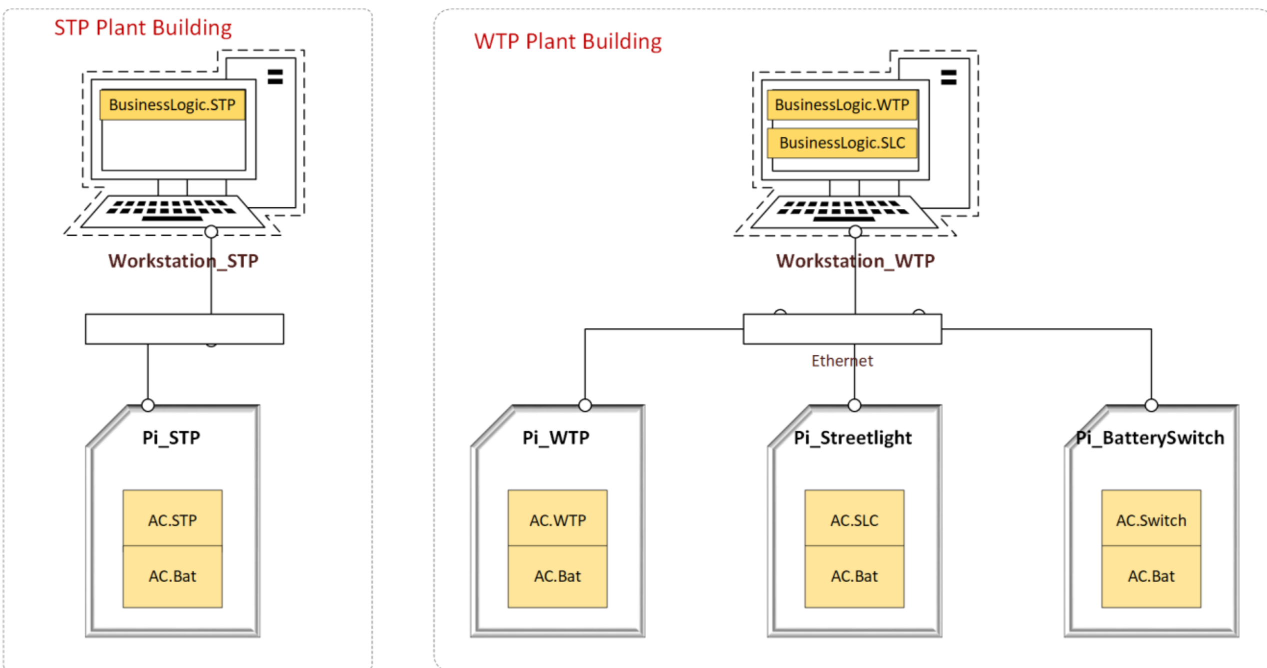

Fig. 3. Communication Protocols used for communication between hardware-software entities

2.4 Application layout view

The application layout view in figure 4 shows the software application that will be used for monitoring, planning and controlling the hardware. Irrespective of the hardware deployment, the Layer-2 and Layer-3 components would be developed in fortiss's energy management tool called iEMS. The plant level instances of iEMS (i.e iEMS on Raspberry PIs) talk directly with the devices on the field. The industry 4.0 standard 4DIAC application would be deployed in sonnenBatteries. This helps in monitoring and controlling of sonnenBatteries with the iEMS system. The energy optimization algorithms would be implemented in GAMS (General Algebraic Modeling System) tool. A special interfacing tool called "OpcGAMS" would be developed to integrate and communicate GAMS tool with iEMS controller applications. All the control logic would be included in controller instances of iEMS.

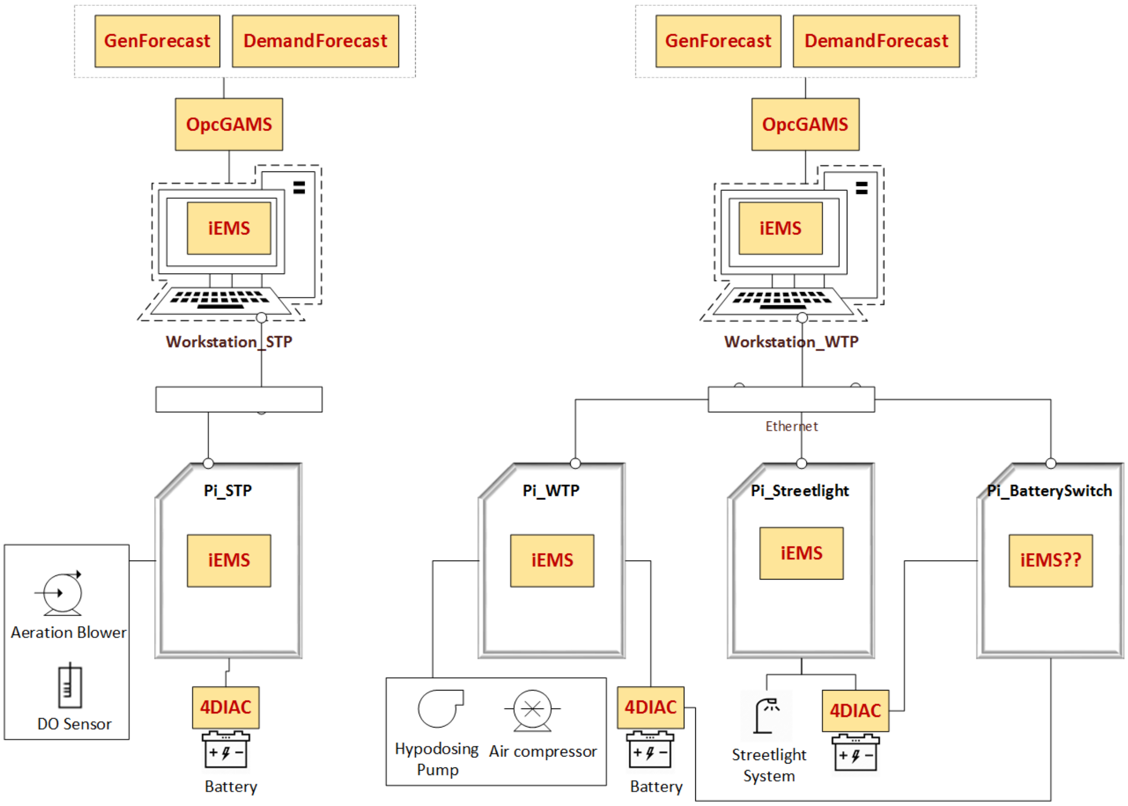

Fig. 4. Hardware-software view w.r.t to the WTP, STP and Streetlight controller

2.5 Software Component View

intelligent Energy Management System (iEMS) is a decentralized and distributed energy management system developed in JAVA programming language. It can be used in microgrid networks to intelligently manage the energy resources and connected loads. The iEMS software application is based on the OSGi framework, which provides ease of development and deployment of isolated services. These services or bundles can be added, removed, or replaced at runtime without interfering with the overall system at runtime. By using a modular and component-based approach, we ensure a highly flexible deployment of the system. Hence, iEMS can be deployed on across several machines as a distributed system. It can be deployed on numerous hardware. For example, Raspberry Pi, Beagle Bone, Desktop computers, laptops, embedded servers etc.

The software component view of STP usecase is presented in figure 5. BusinessLogic.STP is an instance of iEMS, which consists of core components, along with highlevel components such as Forecasting, UI, ECOWET and actuator-client components like OPCUA.GAMSClient and OPCUA.STPClient. As mentioned before, OpcGAMS is an interfacing tool for optimization tool (GAMS) which hosts an OPC UA server. OPCUA.GAMSClient is a client component that sends and receives optimization inputs and outputs to/from OpcGAMS OPC UA server. All the components exchange information and data through RabbitMQ message bus. Plant instance of iEMS consists of iEMS core components and ActuatorClient components to interact with sonnenBatteries and field devices. The recorded data from field devices can be accessable through OPC UA server of plant instance of iEMS (Pi_STP). BusinessLogic instance of iEMS would access that recorded data through OPCUA.STPClient. OPCUA.BAT actuator client component interacts with OPC UA server instance of 4DIAC application hosted in sonnenBatterie. 4DIAC is an open source IEC 61499 implementation with an Integrated Development Environment (IDE) and a Run Time Environment (RTE).

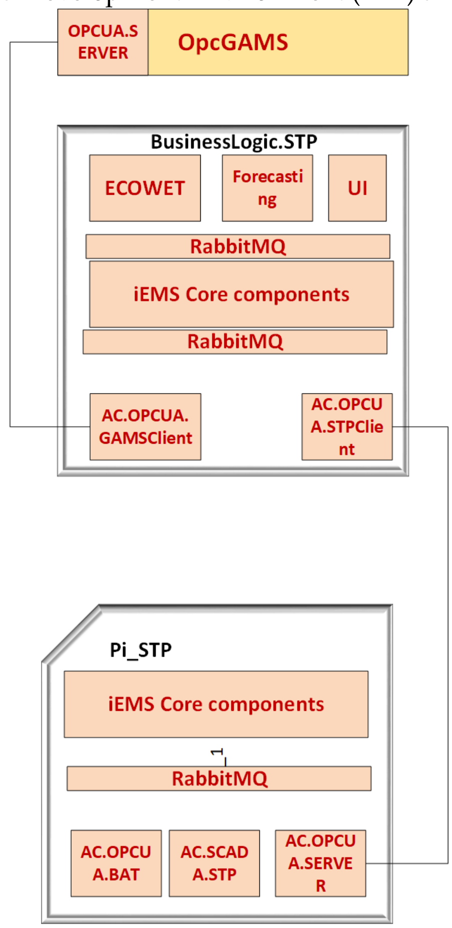

Fig. 5. Software Applications communicating with each other at STP

For WTP and Street lighting usecases, Controller instance of iEMS , is similar to STP usecase, consists of iEMS core components, along with highlevel components such as Forecasting, UI, ECOWET and actuator-client components like OPCUA.GAMSClient and OPCUA.Client. All the components exchange information and data through RabbitMQ message bus. Plant instance of iEMS consists of iEMS core components and ActuatorClient components to interact with sonnenBatteries and field devices. Controller instances of iEMS for both WTP and Streetlighting would be deployed in workstation located at WTP.

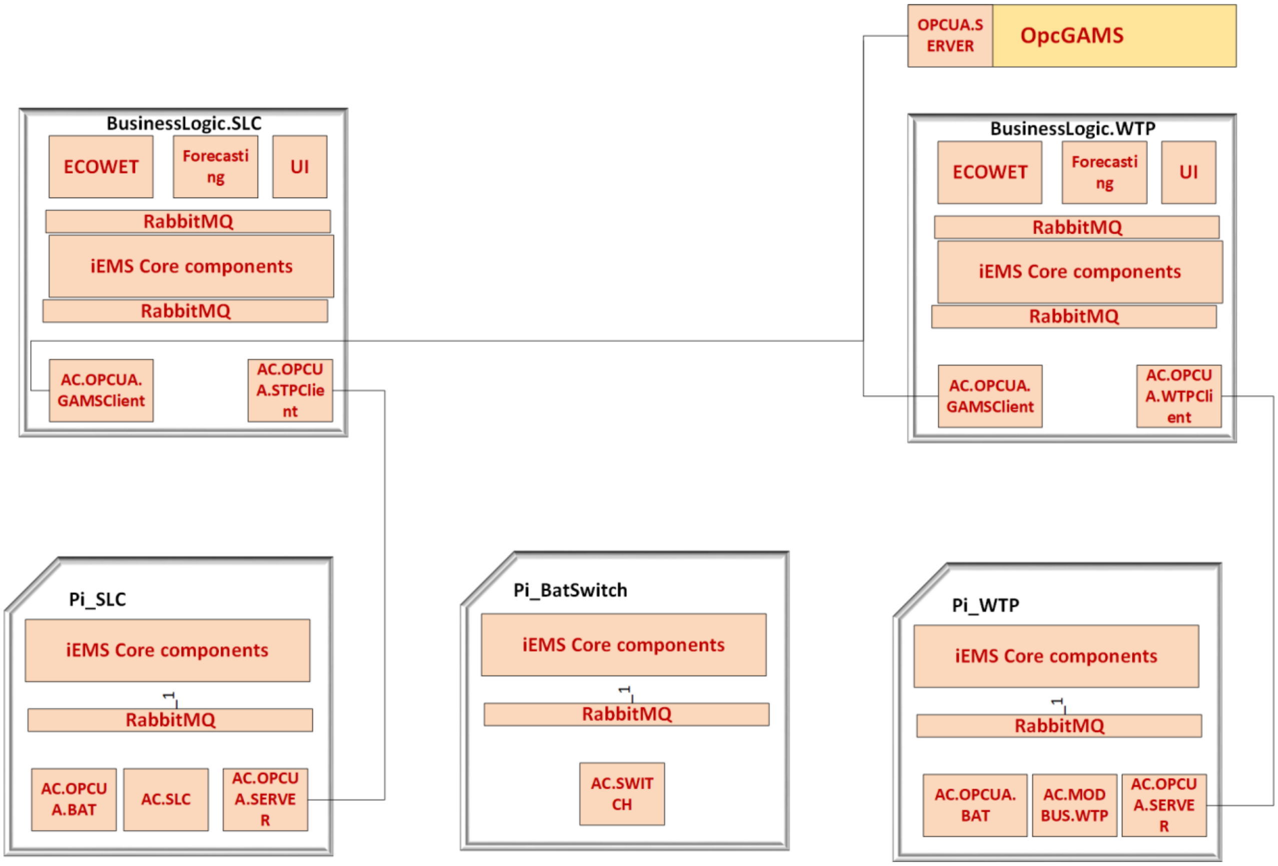

Fig. 6. Software Applications communicating with each other at WTP

3. Suitability and appropriateness of Various Architectural View

The suitability and appropriateness of the architecture can be assessed after implementing and deploying the software components in the Testbed. The suitability of the design can be argued using following factors:

a) Support to multiple communications: As shown in figure 2, the software applications will support various communication protocols. OPC UA was developed for industrial automation, but the use of OPC UA in the energy management will establish the extensive use of OPC UA in microgrids.

b) Support to multiple software applications: As shown in figure 4, various software applications communicate with each other. Each application has unique capabilities such as iEMS is capable of distributed deployment and decision making, GAMS modeling tool is capable of formulating complex optimization problems and 4diac is based on IEC 61499 standard for measurement and control. This cluster of innovative software applications will make the decision-making process faster and accurate.

c) Support to Distributed decision-making: In figure 6, five instances of iEMS are shown. Each iEMS instance is capable of monitoring, planning and executing decisions. The resource intensive tasks like optimization can be carried out on the workstation, while less intense tasks like daily cache clearance can be carried by individual iEMS.

4. Summary

In this report, the design principles and various architecture designs have been presented. Various views of the system emphasize on certain aspects. The team working in the projects has various expertize such as software designers, data scientists, power domain engineers, project managers etc. This document will help them understand the system and its capabilities. The implementation of the proposed design will be carried out at GIFT location. The evaluation of the architecture will be carried out by implementing at both Indian and German locations.