# A Smart Energy Management System for Cross-sectoral Coupling and Water-energy Nexus

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Abstract: Cross-sectoral coupling is one of the newly emerging research topics that refers to the idea of interconnecting and integrating the energy consuming sectors like buildings (heating and cooling), transport, water supply systems and other energy intensive process with the power-producing sector. The cross-sectoral integration of the water-energy nexus and the sustainability issues surrounding the availability of clean water and energy has drawn the attention to the problem from all around the globe. Smart decision-making and control systems can improve the efficiency of the overall operation of both water and energy systems. At a technological level, there have been attempts to optimize coupling points between the electricity and water systems to increase efficiency of both. Most of the optimization and smart decision-making systems focus on energy system and consider heterogeneous infrastructure in the form of energy consumption devices. In the scope of water-energy nexus, energy efficient decisions would have implications on water infrastructure. Tools and platforms for water-energy nexus are required, such that planning and executing the decisions and their implications on both energy and water infrastructure can be seen. Most of the existing controllers are specifically designed to efficiently serve either energy or water systems. In this paper, we propose a software architecture for the platform that is capable of monitoring, controlling, decision making and analysing the effect of decisions for water and energy nexus.



## 1 INTRODUCTION

Water-energy nexus is the concept that refers to the relationship between the water used for energy production, including both electricity and fuel sources such as oil and natural gas, and the energy consumed to extract, purify, deliver, heat/cool, and dispose of water and wastewater (Spang et al., 2014). It is inextricably linked to the core of environmentally sustainable smart cities as shown in Figure 1. Clean and sustainable water supplies and low carbon energy access are the essential building blocks for economies, health and quality of life.

Present day energy and water systems are interdependent and have to be addressed together (Olsson, 2012). Extraction, treatment, carriage and management of drinking water and treatment of wastewater are both dependent on a substantial amount of electrical energy. Huge volumes of water are drawn and consumed from water bodies every day for electricity generation. Rapid population growth, increased per capita demand, distortion of availability of fresh water due to climate change is driving up the demand for both electricity and water. These trends raise concerns about the robustness and sustainability of today's electricity and water systems over the coming decades.

Scarcity in either water or energy will create aggravated shortages in both. An appreciation of the scale of the challenge presented by the energy-water nexus can be acquired by a consideration of the degree of coupling between the two systems.

The demand on water resources in the urban environment requires more efficient water management to deal with urbanization and population growth, more complex water facilities in new buildings, and the deterioration of existing water infrastructure. There is an urgent need to (a) reduce the water extracted for use in buildings, (b) promote water savings, and (c) stop wastage. The ability to provide appropriate means to intelligently monitor the water network and analyze real time information with the help of smart technologies will provide optimized alternatives to take better actions to



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balance the conflict between water demand and provision.

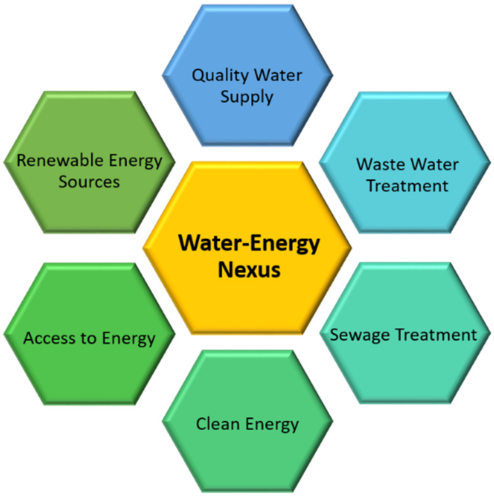


Figure 1: Water-energy nexus: Building blocks for a sustainable smart city.

The present day water management and energy management are primarily centrally controlled without any interlinking between both of them. The central control is usually susceptible to downtimes due to latency, connection loss, damage etc. Current management systems, often, pose water quality concerns, complex coordination issues between energy savings, and operational and maintenance issues (Cherchi et al., 2015). A loosely coupled, distributed control and monitoring environment is needed for betterment in both water and energy management. A distributed control with central coordination can produce a localized and robust control with a platform that collects and analyzes more data.

It is possible to address the water-energy nexus by advanced energy efficiency and water management algorithms, distributed monitoring and control strategies, state-of-the-art metering infrastructure, and optimal utilization of distributed energy resources. Through the pervasive deployment of the Internet of Things (IoT), and advanced Information and Communication Technologies (ICT), big energy data will be generated in terms of volume, speed, and variety. Smart data analysis of this data can bring enormous benefits to the energy efficiency and management (Pindoriya et al., 2018). However, it must be processed and communicated in an energy efficient manner.

It is important to note that the challenges presented by the energy-water nexus and sector coupling are location specific. The mix of available water sources, electricity generation options, local effects of climate change, and societal requirements together determine the sustainability and robustness concerns associated with the nexus. This paper presents an architecture for the platform that is capable of monitoring, controlling, decision making and analyzing the effect of decisions for water and energy nexus through sector coupling. Section II presents a brief review of issues covered in various publications on or related to the energy-water nexus and sector coupling. In Section III, system context, application area, requirements and proposed system architecture. Section IV offers some insights of the proposed platform. Section V concludes the work and presents potential directions for future work.

## 2 BACKGROUND

Water management primarily focuses on the following aspects 1) Improving allocation through quicker decision-making and control. 2) Conservation of the resources (energy, water, and other natural resources) available by improving the efficiency and recycling the wastewater. Energy management focuses on 1) Saving energy by metering the energy consumption and collecting the data. 2) Reducing dependence on the fossil fuels that are becoming increasingly limited in supply. 3) Optimal utilization of Renewable and distributed energy resources (BizEE Energy Lens, 2019).

Literatures (Public Utilities Board Singapore, 2016; Diniz et al., 2015) discuss the strategies to improve the energy efficiency of the water supply systems. Energy management strategies using short-term water consumption forecasting and computer modelling to minimize cost of pumping operations has been explored in (Jentgen et al., 2007; Bagirov et al., 2015) respectively. Studies have successfully demonstrated that integrated energy and water management system provides a number of economic, environmental and operational benefits, without compromising on water quality and energy supply objectives (Cherchi et al., 2015; Jentgen et al., 2007; Douville & Macknick, 2011).

However, there are limited studies addressing the water-energy nexus using sector coupling (Green et al., 2017; Vakilifard et al., 2018). Most of the approaches highlight the challenges and the need for integration of renewable energy usage for multiple sectors like food, water, agriculture etc. None of the approaches proposed suitable platform architecture for an integrated energy and water management system.

In this work, we propose an approach where we address the integrated energy and water management system by linking various branches of the energy sector (sector coupling) and utilizing the ICT, distributed monitoring and optimal utilization and control of distributed energy resources (renewable energies and energy storage) for water infrastructure. Additionally, we propose a software architecture for the platform that is capable of monitoring, controlling, decision making and analyzing the effect of decisions for water and energy nexus.

# 3 ARCHITECTURE OVERVIEW

A Smart Energy Management System for cross-sectoral coupling and water-energy nexus should meet following requirements:

- Real-time monitoring support: collecting and analyzing data from various sensors.
- Support multi-communication protocol: In order to seamlessly integrate with various field devices and sensors irrespective of their communication protocol.
- Smart decisions based on collected data: Making smart decisions based on the advanced optimization techniques and data analysis.
- Distributed controlling: To control complex processes that can be geographically disseminated using networked control elements that are distributed throughout the system.
- Modular in nature: Easy to maintain, deploy, update, and develop the software code components.
- Flexible and Scalable: Scalable from building level to city/municipality level

A service-oriented architecture with open standard protocols, event-driven programming model, service bus, and integrative computational and data infrastructure is well suited for building robust smart energy management system for water-energy nexus (Mora et al., 2012; Berres et al., 2017) [11, 12]. We propose a generic architecture for such Energy Management System presented in the Figure 2.

The bottom layer has software components interfacing with the physical hardware devices such as advanced metering, SCADA devices, IoT sensors connected at the major process equipment in the critical infrastructures like Water Treatment Plant (WTP), Sewage Treatment Plant (STP), street lighting system etc. that are spread spatially across the field. This layer is primarily intended for realtime monitoring and controlling of the field devices. Custom monitoring and local control logic are embedded in the interfaces that can exchange data in device specific protocol (such as MODBUS, REST API, OPC UA, MBUS, MQTT etc.). It is distributed in nature with each interfacing component act standalone. So malfunctioning of any of the components does not affect the rest of the components. It is also capable of local decision making in case of communication interruption/failures with higher level components or in emergency situations. These components act as controllers for respective field devices with which they communicate. Due to this semi-autonomous capability of this layer, distributed controlling is made possible.

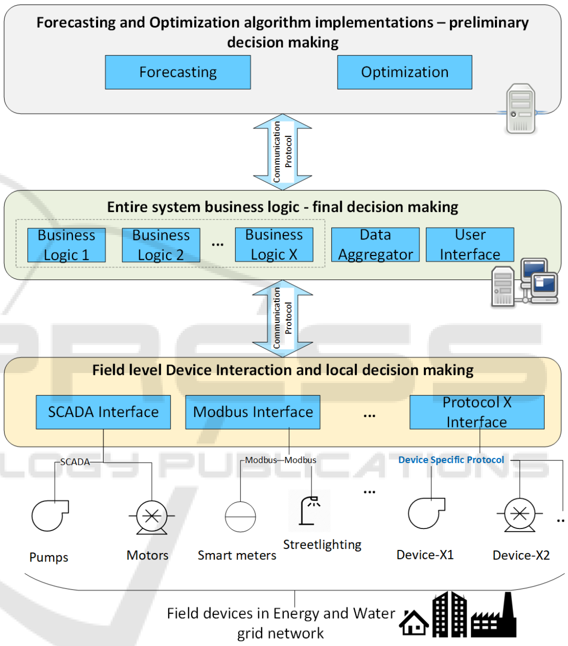


Figure 2: Proposed architecture for Energy Management System for cross-sectoral coupling and water-energy nexus.

Middle layer consists of business logic components. It receives the inputs from bottom layer components and forwards it to higher level components for preliminary decision making. Though it usually follows the decisions from higher-level components, during exceptional situations, it has the final say over how the field devices should behave. This would help in handling the exceptional flow of events. One business logic component may interact with multiple device interfacing components in the bottom layer.

The improvement of energy efficiency and effectiveness of water management and optimal utilization of energy/water can be achieved by incorporating advanced optimization algorithms and techniques. Top layer has forecasting and optimization components based on advanced data analytics, machine learning techniques, and multi-dimensional statistical tools. For example, implementation of optimization components for an array of energy cost reduction strategies operating within designated constraints.

# 4 CASE STUDY

The testbed is located in GIFT City – Gujarat International Finance Tech City of Gujarat, India. The GIFT city envisions a smart city infrastructure with efficient water and energy distribution networks in a distributed manner. The testbed comprises of a WTP and street lighting cluster (which is also located close to WTP) as shown in the Figure 3. Water infrastructure in GIFT is designed to provide "potable-water-in-all-taps" with the total water requirement of over 60 Million Litters per day (MLD). The present process of WTP consists mainly of the filtration process, dual media filters (made up of sand and gravel) and micro cartridge filters. Dosing is one of the main tasks in chemical and process engineering in water treatment and as a result, hypo dosing pumps (HDPs) and air compressors are used in WTP.

The energy intensive loads like Hypo dosing pump, Air compressor, etc. are connected to Water treatment plant (WTP) feeder. Along with the WTP loads, Solar Photovoltaic (PV) panels with Inverters and Batteries are also connected to the feeder. Similarly, Streetlights, Solar PV panels with inverter and battery are connected to Street lighting feeder. Additionally, there are interconnecting switches connected to both feeders that facilitate switching of batteries from one feeder to the other.

It has been observed that electricity generation from renewable sources can be used to operate processes like water supply, sewage plant, street lighting etc. whereas in case of oversupply of electricity from renewable sources, water pump or other city processes can be made operational, thus making the balance of supply and demand in the system. This can be achieved by developing an intelligent optimization framework and integrated into the system. To check viability and feasibility, couple of use cases were identified at the Testbed based on load demand, operating duration, and switching on-off pattern.

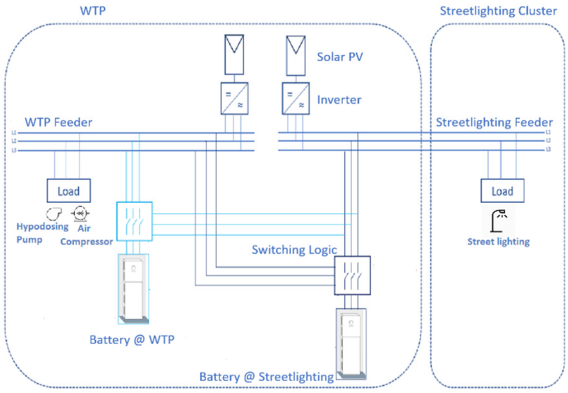


Figure 3: Testbed and use cases at GIFT city.

## 4.1 Use Cases

### 4.1.1 Use Case-1

Solar PV and Battery Energy Storage System (BESS) installations will be utilized effectively to fulfil the energy demand of the HDP at WTP in GIFT city. Therefore, it can be anticipated that, by automating the process control and energy flow to HDP, the dosing process at WTP is well maintained. At the same time, by effectively utilizing the solar PV and BESS systems, the power drawn from the utility grid can be reduced considerably which will eventually reduce the operating cost. Similarly, Intelligent street lighting also has significant potential in energy saving for smart cities. An additional solar PV and BESS system installations at GIFT city will be utilized to supply power to the street light cluster. By automating the process of energy flow and switching of street lighting systems, a significant reduction in operating cost and power drawn from the utility can be achieved.

The main objective of this use case is to maximize the use of solar PV system and battery to support the load of HDP and air compressor in WTP and minimize the overall cost of energy purchased from the grid.

### 4.1.2 Use Case-2

Intelligent sharing of energy between multiple batteries can further enhance the efficient utilization of Battery storage systems. This can be achieved by switching the batteries between the feeder lines (WTP and Street lighting feeders) based on certain optimization criteria and reducing the energy utilized from the power grid. By this way, operation costs and dependency towards the grid can be further reduced.

## 4.2 System Architecture

A flexible, extensible, lightweight and self-similar architecture has been deployed at the testbed in order to implement the identified use cases that were mentioned above. It follows a layered and component-based approach to ensure scalability, flexibility and extensibility with state-of-the-art communication protocols. An overview of the system is illustrated in Figure 4.

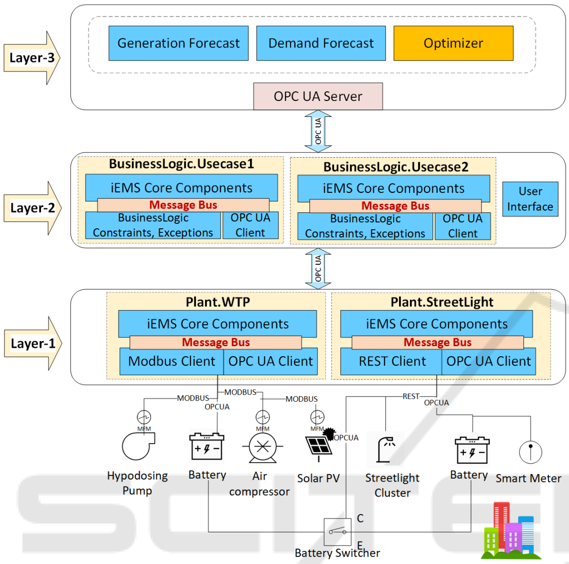


Figure 4: Software architecture of proposed integrated water and energy management platform at the Testbed.

The Layer-1 and Layer-2 components are developed based on an in-house energy management tool called iEMS. The intelligent Energy Management System (iEMS) is a decentralized and distributed energy management system developed in JAVA programming language. It can be used in micro grid 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 across several machines as a distributed system. It supports numerous hardware. For example, Raspberry Pi, Beagle Bone, Desktop computers, laptops, embedded servers etc.

The iEMS core components include library bundles responsible for information exchange, database management, message bus interfacing components, user management, and overall system health check monitoring components. All the components exchange information and data through RabbitMQ message bus.

The bottom layer (Layer-1) has iEMS instances along with interfacing components (Modbus client and OPC UA client) that can communicate with field devices at the water treatment plant and street lighting cluster. The data is exchanged with aeration blower, hypo dosing pump, air compressor, and energy meters over MODBUS protocol, street lighting using REST protocol and batteries through the OPC UA protocol. Plant. WTP bundle measures the energy consumption of hypo dosing pumps, compressor and monitor the battery parameters (like State-of-Charge, voltage, temperature, etc) from battery management system (BMS). The IEC 61499 standard compliant 4DIAC application is deployed in batteries, which interacts with battery management system and helps in monitoring and controlling of batteries over OPC UA interface. Plant. Streetlight software bundle monitors the energy consumption of streetlight and battery's SOC. Instances of iEMS and other components in this layer are deployed on Raspberry PIs and are located close to the field devices.

Layer-2 also consists of instances of iEMS along with additional components. It receives the measured data as inputs and forwards it to Optimizer component for decision-making. The business logic and flow of events are embedded in this layer. The business logic components with respect to identified use cases (BusinessLogic.Usecase1 and BusinessLogic.Usecase2) are included in this layer. They act as coordinators. The control signals are sent to field devices via the components at Layer-1. Further use cases, which would be identified in the future, would also be included in this layer.

Decision making involves planning capabilities, which are provided by the top most layer (Layer-3). Optimization and forecasting algorithms are implemented (Generation. Forecast, Demand. Forecast and Optimizer) using machine learning algorithms and optimization tools. The energy optimization algorithms are implemented in GAMS (General Algebraic Modeling System) and MATLAB tools. A special interfacing tool has been developed to integrate and communicate GAMS and MATLAB tools with the OPC UA server.

The communication channels and protocols at the testbed are chosen based on various considerations such as distance between the plants, physical location of field devices, support to the protocol by different hardware and data latency requirements. Most of the installed hardware supports MODBUS or OPC UA communication protocol. The bottom level software components (Layer-1) are deployed on Raspberry Pis and higher level components (Layer-2 and Layer-3) are deployed in Windows operating system based workstations. The Raspberry Pis and workstations are connected through Ethernet/LAN cables. Information exchange between all the three layers would happen through the OPC UA protocol.

# 5 CONCLUSIONS

Coupling of cross-commodity infrastructure and optimal integration of distributed energy resources is a challenge for smart cities. In this paper, we presented an integrated water and energy management platform architecture to manage the water and energy infrastructures at GIFT city using ICT. The testbed identified for this study are STP, WTP, and street light clusters attached to WTP which are energized by solar PV, BES, and utility grid. A detailed description of the testbed is also presented and then the use cases with their functional requirements from the test bed have been identified. A three layered component based architecture has been proposed to address the energy management and real time control of the use cases where a multilevel controlling and monitoring system is proposed. The proposed platform has the advantage of supporting heterogeneous device protocols, flexible deployment of the system, eliminating the latency and interruption in management of infrastructure. Therefore, an efficient and uninterrupted water and energy distribution is possible at the testbed.

As a future step, the implementation will be carried out in the real environment to test the data collection and the controlling based on the optimization values. Furthermore, new use cases will be identified and proposed platform will be evaluated through further research work in the future.

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# REFERENCES

Spang, E. S., Moomaw, W. R., Gallagher, K. S., Kirshen, P. H., and Marks, D. H. (2014). The water consumption of energy production: an international comparison. Environmental Research Letters, 9(10), 105002.

G. Olsson 2012. Water and Energy: Threats and Opportunities. London: IWA Publishing, 2012.

Cherchi, C., Badruzzaman, M., Oppenheimer, J., Bros, C. M., & Jacangelo, J. G. (2015). Energy and water quality management systems for water utility's operations: A review. Journal of Environmental Management, 153, 108–120.

Pindoriya, N., Duchon, M., Gupta, P. K., Pampana, V., Singh, S. N., Giza, J., Hackenberg, B., Rajput, A. K., Jethi, J. 2018. Intelligent Hardware-Software Platform for Efficient Coupling of Water-Energy Nexus in Smart Cities: A Conceptual Framework. In Proceedings of Mobility IoT (Guimarães, Portugal, November 21-23, 2018).

BizEE Energy Lens. (2019). The What, Why, and How of Energy Management. (March 2001). Retrieved October 16, 2019 from https://www.energylens.com/articles/energy-management.

Public Utilities Board Singapore Pan_Ju_Khuan@ pub. gov. sg. (2016). Managing the water distribution network with a Smart Water Grid. Smart Water, 1, 1-13.

Diniz, A. M. F., de Oliveira Fontes, C. H., Da Costa, C. A., & Costa, G. M. N. (2015). Dynamic modeling and simulation of a water supply system with applications for improving energy efficiency. Energy Efficiency, 8(2), 417-432.

Jentgen, L., Kidder, H., Hill, R., & Conrad, S. (2007). Energy management strategies use short ‐ term water consumption forecasting to minimize cost of pumping operations. Journal ‐ American Water Works Association, 99(6), 86-94.

Bagirov, A. M., Barton, A. F., Mala-Jetmarova, H., Al Nuaimat, A., Ahmed, S. T., Sultanova, N., & Yearwood, J. (2013). An algorithm for minimization of pumping costs in water distribution systems using a novel approach to pump scheduling. Mathematical and Computer Modelling, 57(3-4), 873-886.

Douville, C., & Macknick, J. (2011, January). Energy Usage and Management at a Large Wastewater Treatment Facility in Boulder, Colorado. In ASME 2011 International Mechanical Engineering Congress and Exposition (pp. 653-659). American Society of Mechanical Engineers.

Green, Jennifer, Amit Gandhi, Éadaoin Ilten, Brennan Lake, Vandana Pandya, Sara Lynn Pesek, Jonars Spielberg, and Christina Sung (2017). "Reports from CITE" Solar Powered Water Pumps Evaluation in India".".

Vakilifard, Negar, Martin Anda, Parisa A. Bahri, and Goen Ho (2018). "The role of water-energy nexus in optimising water supply systems–Review of techniques

and approaches." Renewable and Sustainable Energy Reviews 82: 1424-1432.
Mora, D., Taisch, M., Colombo, A. W., & Mendes, J. M. (2012, July). Service-oriented architecture approach for industrial “system of systems”: State-of-the-art for energy management. In IEEE 10th International Conference on Industrial Informatics (pp. 1246-1251). IEEE.
Berres, A., Karthik, R., Nugent, P., Sorokine, A., Myers, A., & Pang, H. (2017, December). System Architecture Development for Energy and Water Infrastructure Data Management and Geovisual Analytics. In AGU Fall Meeting Abstracts.